

DOE/NASA CONTRACTOR
REPORT

DOE/NASA CR-161603

SOLAR HEATING, COOLING AND DOMESTIC HOT WATER SYSTEM
INSTALLED AT COLUMBIA GAS SYSTEM SERVICE CORPORATION,
COLUMBUS, OHIO

Prepared from documents furnished by

Columbia Gas System Service Corporation
1600 Dublin Road
Columbus, Ohio 43215

Under DOE Contract EG-77-A-01-4089

Monitored by

National Aeronautics and Space Administration -
George C. Marshall Space Flight Center, Alabama 35812

For the U. S. Department of Energy

(NASA-CR-161603) SOLAR HEATING, COOLING AND N81-14394
DOMESTIC HOT WATER SYSTEM INSTALLED AT
COLUMBIA GAS SYSTEM SERVICE CORPORATION,
COLUMBUS, OHIO Final Report (Columbia Gas
Corp.) 123 p HC A06/MF A01 CSCL 10B G3/44 29532
Unclas

U.S. Department of Energy

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161



Solar Energy

NOTICE

This report was prepared to document work sponsored by the United States Government. Neither the United States nor its agents the United States Department of Energy, the United States National Aeronautics and Space Administration, nor any federal employees, nor any of their contractors, subcontractors or their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represent that its use would not infringe privately owned rights.

NOTICE

THIS DOCUMENT HAS BEEN REPRODUCED FROM THE BEST COPY FURNISHED US BY THE SPONSORING AGENCY. ALTHOUGH IT IS RECOGNIZED THAT CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED IN THE INTEREST OF MAKING AVAILABLE AS MUCH INFORMATION AS POSSIBLE.

SOLAR HEATING, COOLING AND DOMESTIC HOT WATER
SYSTEM INSTALLED AT COLUMBIA GAS SYSTEM SERVICE
CORPORATION, COLUMBUS, OHIO - FINAL REPORT

Columbia Gas System Service Corporation
Columbus, Ohio

November 1980


1. REPORT NO. DOE/NASA CR-161603		2. GOVERNMENT ACCESSION NO.		3. RECIPIENT'S CATALOG NO.	
4. TITLE AND SUBTITLE Solar Heating, Cooling and Domestic Hot Water System installed at Columbia Gas System Service Corp., Columbus, Ohio - Final Report (AH-45376)				5. REPORT DATE November, 1980	
				6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S)				8. PERFORMING ORGANIZATION REPORT #	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Columbia Gas System Service Corporation 1600 Dublin Road Columbus, Ohio 43212				10. WORK UNIT NO.	
				11. CONTRACT OR GRANT NO. EG-77-A-01-4089	
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Department of Energy, Conservation and Solar Energy Washington, DC 20585				13. TYPE OF REPORT & PERIOD COVERED Contractor - Final Report	
				14. SPONSORING AGENCY CODE	
15. SUPPLEMENTARY NOTES This work was done under the Technical Management of Mr. Douglas Westrope, George C. Marshall Space Flight Center, Alabama, 35812.					
16. ABSTRACT <p>This document is the Final Technical Report of the Solar Energy System located at the Columbia Gas Corporation, Columbus, Ohio. The Solar Energy System installed in the building has 2,978 ft² of Honeywell single axis tracking, concentrating collectors and provides solar energy for space heating, space cooling and domestic hot water. A 1,200,000 Btu/hour Bryan water-tube gas boiler provides hot water for space heating. Space cooling is provided by a 100 ton Arkla hot water fired absorption chiller. Domestic hot water heating is provided by a 50 gallon natural gas domestic storage water heater.</p> <p>This report includes extracts from the site files, specification references, drawings, installation, operation and maintenance instructions.</p>					
17. KEY WORDS			18. DISTRIBUTION STATEMENT UC59a Unclassified-Unlimited  WILLIAM A. BROOKSBANK, JR. Mgr., Solar Energy Applications Proj.		
19. SECURITY CLASSIF. (of this report) Unclassified		20. SECURITY CLASSIF. (of this page) Unclassified		22. PRICE NTIS	

TABLE OF CONTENTS

I.	Program Summary	1
II.	Highlights Building Description	3
III.	Building Energy Conservation	6
IV.	Solar Energy System Description	10
	A. Solar System Diagram	
	B. Solar System Operation and Control	
	C. Solar Collectors	
	D. Solar Collector Loop Heat Transfer Fluid	
	E. Solar Heat Exchanger	
	F. Solar Collector Loop Pump	
	G. Thermal Energy Storage Tank and Enclosure	
	H. Storage Loop Pump	
	I. Domestic Hot Water Preheat System	
	J. Emergency Power System	
V.	Solar Energy System Installation	34
	A. Consulting Engineer	
	B. Construction Subcontractors	
	C. Construction Schedule	
	D. Construction Problems and Resolution	
VI.	Solar System Acceptance Testing	42
VII.	Post Installation Solar System Modifications	45
	A. Sensor Modifications	
	B. Solar Collector Drive Motor Modifications	
	C. Solar Collector Speed Reducer Repair	
	D. Solar Collector Absorber Tube Housing Modifications	
	E. Solar Collector Panel Modifications	
	F. Addition of Solar Collector Panel Counterweights	
	G. Storage Tank Insulation Modification	
	H. Sun Tracking Controls Replacement	
	I. Solar Collector Wakeup Sensor Replacement	
VIII.	Solar System Performance	59

LIST OF FIGURES

Figure 1	- Highlights Building Aerial Photograph	2
Figure 2	- Highlights Building Monthly Energy Consumption	7
Figure 3	- Solar Energy System Schematic	11
Figure 4	- Solar Collector Loop Pump Control Diagram	13
Figure 5	- Solar Collector Control Diagram	15
Figure 6	- Solar Heat Exchanger Bypass Control Diagram	20
Figure 7	- Solar Storage Loop Pump Control	21
Figure 8	- Solar Energy/Natural Gas Switchover Control	24
Figure 9	- Highlights Building Aerial Photograph	26
Figure 10	- Solar Collector Structure	27
Figure 11	- Solar Collector Mounting Detail	28
Figure 12	- Honeywell Collector Line Drawing	29
Figure 13	- Collector Drive Motor and Speed Reducer	30
Figure 14	- Emergency Generator and Transfer Switch	33
Figure 15	- Solar Collector Panel End Cap Damage	48
Figure 16	- Solar Collector Panel Reflective Surface Damage	50
Figure 17	- Solar Collector Counterweights	52
Figure 18	- Highlights Building South Elevation	63
Figure 19	- Highlights Building West Elevation	63
Figure 20	- Highlights Building North Elevation	64
Figure 21	- Highlights Building East Elevation	64
Figure 22	- Highlights Building First Floor Plan	65
Figure 23	- Highlights Building Second Floor Plan	66
Figure 24	- Highlights Building Third Floor Plan	67

LIST OF FIGURES (continued)

	Page
Figure 25 - Torque Tube Torsion Diagram	102
Figure 26 - Torque Tube Twist Diagram	106
Figure 27 - Solar Collector Counterweight Design	108

LIST OF TABLES

Table 1 - Highlights Building Natural Gas Consumption	9
Table 2 - Construction, Instrumentation and Evaluation Schedule	36
Table 3 - Total Solar Energy Available and Solar Energy Collected - 1979 and 1980	60
Table 4 - Beam Solar Energy Available and Solar Energy Collected - 1979 and 1980	61
Table 5 - Reflector Distortion Size and Location	98
Table 6 - Reflector Panel Freeze Damage Histogram	100

LIST OF DRAWINGS

Drawing TCP-1 - Solar Collector Controls	68
Drawing TCP-2 - Change Over Controls	69
Drawing CS-1 - Construction Drawing Index	77
Drawing G-1 - Site Plan and Floor Plans	78
Drawing G-2 - Wall Sections	79
Drawing G-3 - Roof Plan and Details	80
Drawing ME-1 - Mechanical and Electrical Floor Plans	81
Drawing ME-2 - System Diagrams and Details	82
Drawing ME-3 - Electrical Roof Plan and Details	83

APPENDICES

	Page
A. - Highlights Building Photographs	63
B. - Highlights Building Floorplans	65
C. - Solar Energy System Control Drawings	68
D. - Solar System Component Specifications	70
E. - Solar Energy System As-Built Drawings	77
F. - Acceptance Test Plan	84
G. - Solar Collector Panel Damage Analysis	97
H. - Solar Collector Counterweight System Design	101
I. - Solar Energy Utilization	110

I. PROGRAM SUMMARY

The Highlights Building is a 25,000 ft², three story suburban office building located at 2200 West Fifth Avenue in Columbus, Ohio. The solar energy system installed in the building has 2,978 ft² of Honeywell single axis tracking, concentrating collectors and provides solar energy for space heating, space cooling and domestic water heating in the building. Figure 1 is an aerial view of the Highlights Building from the southeast showing the solar collectors in the tracking position.

The Highlights Building solar energy system was designed by the Columbia Gas System Service Corporation. Solar system construction was jointly funded by the U.S. Department of Energy and Columbia. Construction was started in October, 1977 and completed in June, 1978. Installation and startup of the DOE Site Data Acquisition System was completed in August, 1978 as was system acceptance testing. The solar system was operated each work day for the first ten months with some observation by a technician. The solar energy system was placed in fully automatic, unattended operation in May, 1979.

The Highlights Building solar energy system collected 167.5 million BTU's in 1979. The seasonal solar collector field efficiency is currently 20% based on total solar radiation and 34% based on direct solar radiation. The solar energy system is providing approximately 7% of all the current building thermal energy demand.

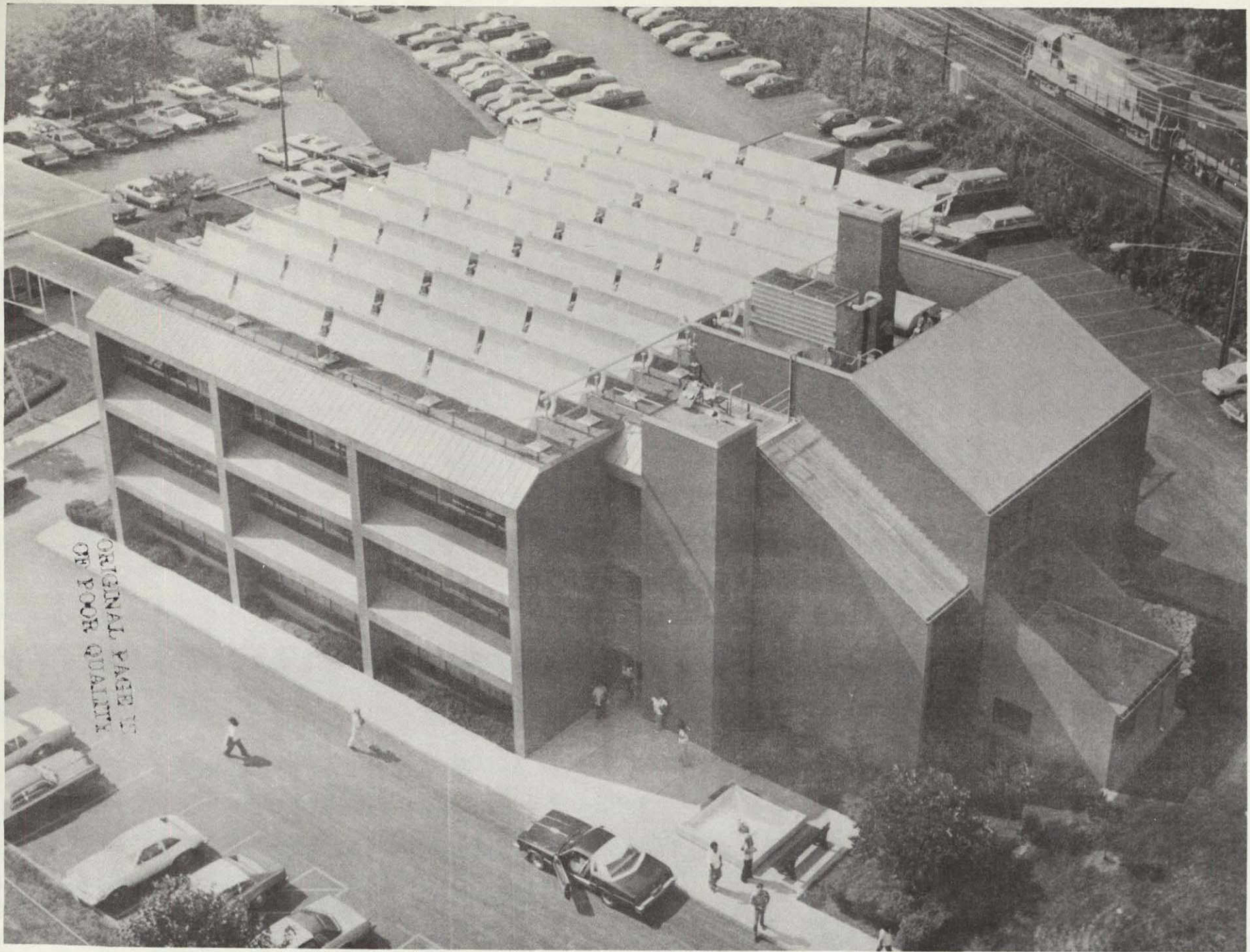


Figure 1

II. HIGHLIGHTS BUILDING DESCRIPTION

The Highlights Building is a three-story 25,000 sq. ft. office building located in a suburban setting in metropolitan Columbus, Ohio. The building is owned by Highlights for Children, Inc., publishers of Highlights For Children magazine and other children's educational materials. The building is leased in its entirety to the Columbia Gas System Service Corporation and is occupied by employees of the Columbia Gas System Service Corporation, the Columbia Gas Distribution Companies and the Columbia Gas Transmission Corporation. Appendix A contains photographs showing the four faces of the building prior to installation of the solar energy system. The front of the building faces south.

The Highlights Building is of pre-stressed concrete column and beam construction with pre-stressed concrete flexcore floors and roof. The exterior of the building is finished with glazed brick veneer. The windows on the south side of the building are recessed to provide shading during the cooling season.

The Highlights Building is occupied 50 hours per week from 7:00 a.m. to 5:00 p.m., Monday through Friday, by approximately 60 persons. Appendix B contains floor layout diagrams for the building. The Columbia Gas System Service Corporation's Stationary Department occupies the first and second floors and the north portion of the third floor of the building. The south portion of the first floor is dedicated to storage of paper stock. The north portion of the first floor is utilized by the Shipping and Receiving Department. The second floor consists of stationary offices, layout area and production facilities. The north portion of the third floor consists

of document assembly, finishing and packaging. The remainder of the third floor consists primarily of office space.

Energy for heating and cooling and for domestic water heating in the Highlights Building is provided by natural gas. A 1,200,000 BTU/hour Bryan water-tube gas boiler provides hot water for space heating and space cooling in the building. In the space heating mode the hot water is distributed to finned coils located in the air handling system on the second and third floors of the building and to finned tube radiators beneath the windows, which control moisture condensation on the surface of the glazing. Heating on the first floor is provided by hot water unit heaters.

Space cooling is provided by a 100 ton Arkla hot water fired absorption chiller. Cooling on all three floors is provided by chilled water finned coils located in air handlers on the second and third floors and on the rear portion of the first floor. Building thermostats are maintained at 65°F during the winter and at 78°F during the summer, with the exception of the Stationary Department press room and work-in-process storage areas which are maintained at 72°F throughout the year.

Domestic water heating in the Highlights Building is provided by a 50 gallon natural gas domestic storage water heater. Storage tank temperature is maintained at 140°F. Primary use for this domestic water is cleaning of photographic plates.

The air distribution system for space conditioning on the second and third floors of the Highlights Building is a two-deck, continuous air volume system. The building was originally designed to provide for concurrent operation of the hot and cold decks, with terminal blending as required by individual zone control

thermostats. The system is currently operated 10 months of the year with either the hot deck or the cold deck activated, depending on the season of the year. The non-conditioned deck recirculates air through the building to provide terminal mixing and permit continuous air delivery in the occupied areas of the building, even when no heating or cooling is required for the room thermostats. For approximately 30 days in the Spring and 30 days in the Fall both the hot deck and cold deck are activated.

III. - BUILDING ENERGY CONSERVATION

The Columbia Gas System Service Corporation implemented a significant energy conservation program in the Highlights Building starting in 1973. Figure 2 is a plot of the monthly energy consumption in the Highlights Building for the years 1973 through 1977.

Columbia's energy conservation program consisted of the following major elements:

1. Reduction of winter thermostat settings from 72°F to 65°F.
2. Increase of summer thermostat settings from 72°F to 78°F.
3. Reduction of building makeup air.
4. Operation of space conditioning system as an economizer cycle, as permitted by outside weather conditions.
5. Reduction of the outdoor air temperature setting which signals operation of the finned tube radiation heaters beneath the building windows.
6. Reduction of the summer boiler firing temperature to improve boiler and absorption chiller performance.
7. Reduction of boiler input and installation of a permanent restrictor in the boiler flue to improve seasonal efficiency.
8. Night and weekend set back of the space heating thermostat to 50°F.
9. Elimination of air-conditioning operation during periods when the building is unoccupied.

HIGHLIGHTS BUILDING MEASURED MONTHLY NATURAL GAS CONSUMPTION

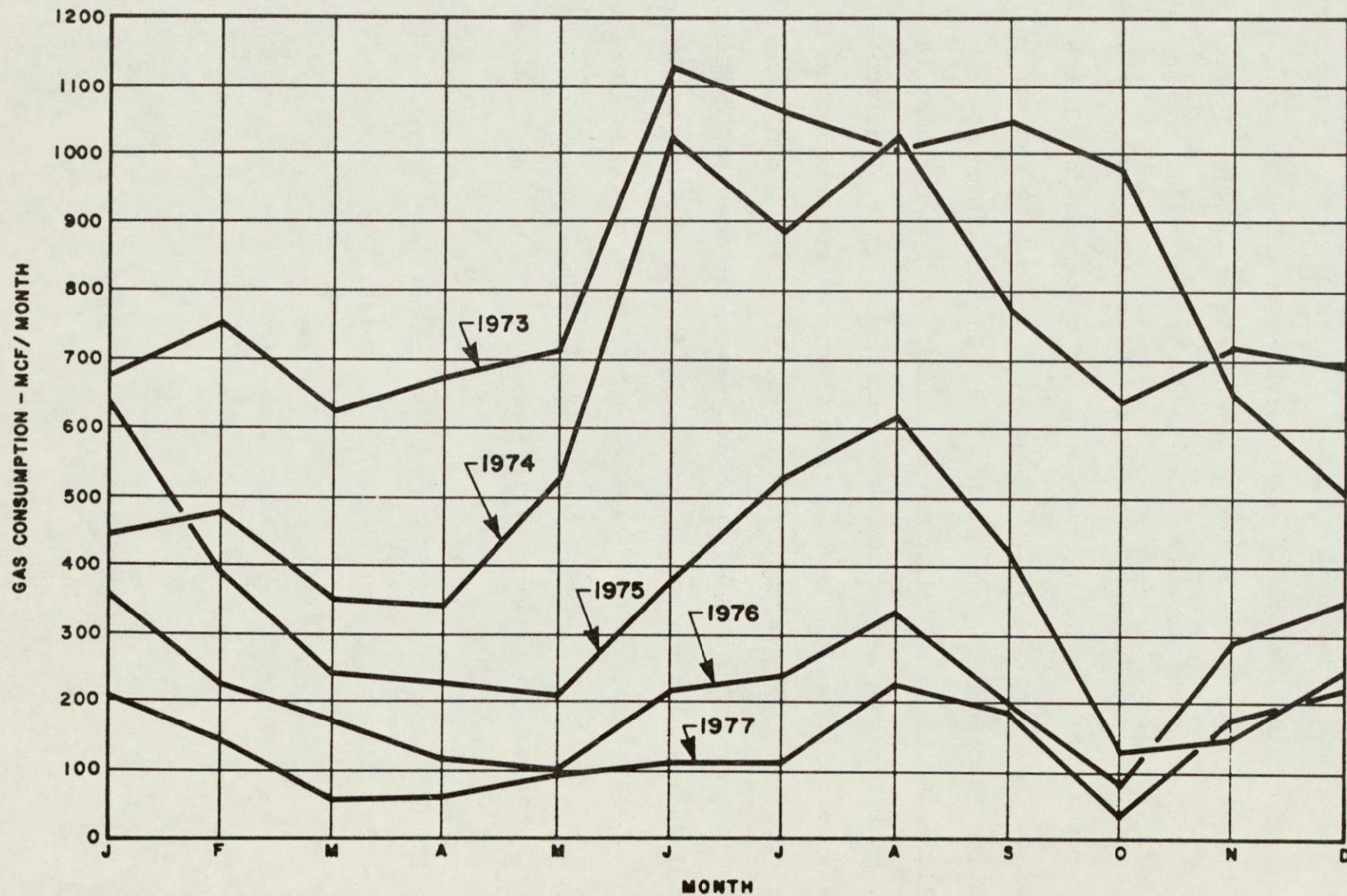


FIGURE 2

The cumulative effect of the energy conservation measures listed above was an 82% reduction in building thermal energy requirement.

In 1978, the Stationary Department experienced problems with curling of work-in-process paper on the production floor over a weekend. The problem with the paper was traced to the loss of temperature and humidity control in the building over the weekend because the building air-conditioning system was not being operated. As a result of this incident, the heating and air conditioning control schedule for the production floor of the Highlights Building was changed to maintain 72°F throughout the year. With these changes in the environmental control schedule for the second floor the annual thermal energy consumption in the Highlights Building has approximately doubled from the minimum consumption achieved during calendar year 1977; however, current thermal energy consumption is still only 45% of the energy consumed during calendar year 1973 when the energy conservation program was initiated. Table 1 presents the building natural gas consumption by month for the years 1973 through 1979.

HIGHLIGHTS BUILDING
NATURAL GAS CONSUMPTION
(In Thousands of Cubic Feet)

	<u>1973</u>	<u>1974</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>
January	680	441	637	353	203	255	314
February	746	476	394	277	151	293	398
March	623	350	239	163	56	196	363
April	670	338	225	118	63	66	226
May	708	527	201	95	97	219	439
June	1120	1031	376	217	110	573	522
July	1051	887	529	239	109	440	417
August	1005	1029	616	337	227	454	455
September	1042	783	412	198	199	501	473
October	964	639	128	73	79	386	349
November	651	720	144	296	126	236	290
December	<u>507</u>	<u>693</u>	<u>249</u>	<u>344</u>	<u>230</u>	<u>351</u>	<u>309</u>
Total	9767	7914	4150	2710	1650	3970	4555

TABLE 1

IV. SOLAR ENERGY SYSTEM DESCRIPTION

A. Solar System Schematic

The Highlights Building solar energy system provides solar energy for space heating, space cooling and domestic hot water as a supplement to the existing natural gas boiler and domestic storage water heater. Figure 3 is a schematic of the solar energy system and its interconnections with the existing building space heating, space cooling and domestic water heating systems. The solar energy system consists of two fluid loops: the primary loop through the solar collectors and, the secondary loop which is an extension of the existing building HVAC loop. The interface between the two loops is the solar heat exchanger. As shown in Figure 3, the solar energy system is installed in parallel with the existing building HVAC boiler and in series with the existing domestic hot water heater.

B. Solar System Operation and Control

The Highlights solar energy system is designed to operate automatically. The control system is comprised of hard wired components and the control logic circuits provide unattended operation of the solar system. Solar system safeties have been incorporated to prevent unsafe conditions from occurring the the event of control system or solar system failure.

The Highlights solar control system has five stand alone control logic circuits that operate independently and provide separate control logic for five major solar subsystems. The following is a discussion of the function and operation of the separate control logic circuits.

SPACE HEATING, SPACE COOLING, AND DOMESTIC HOT WATER

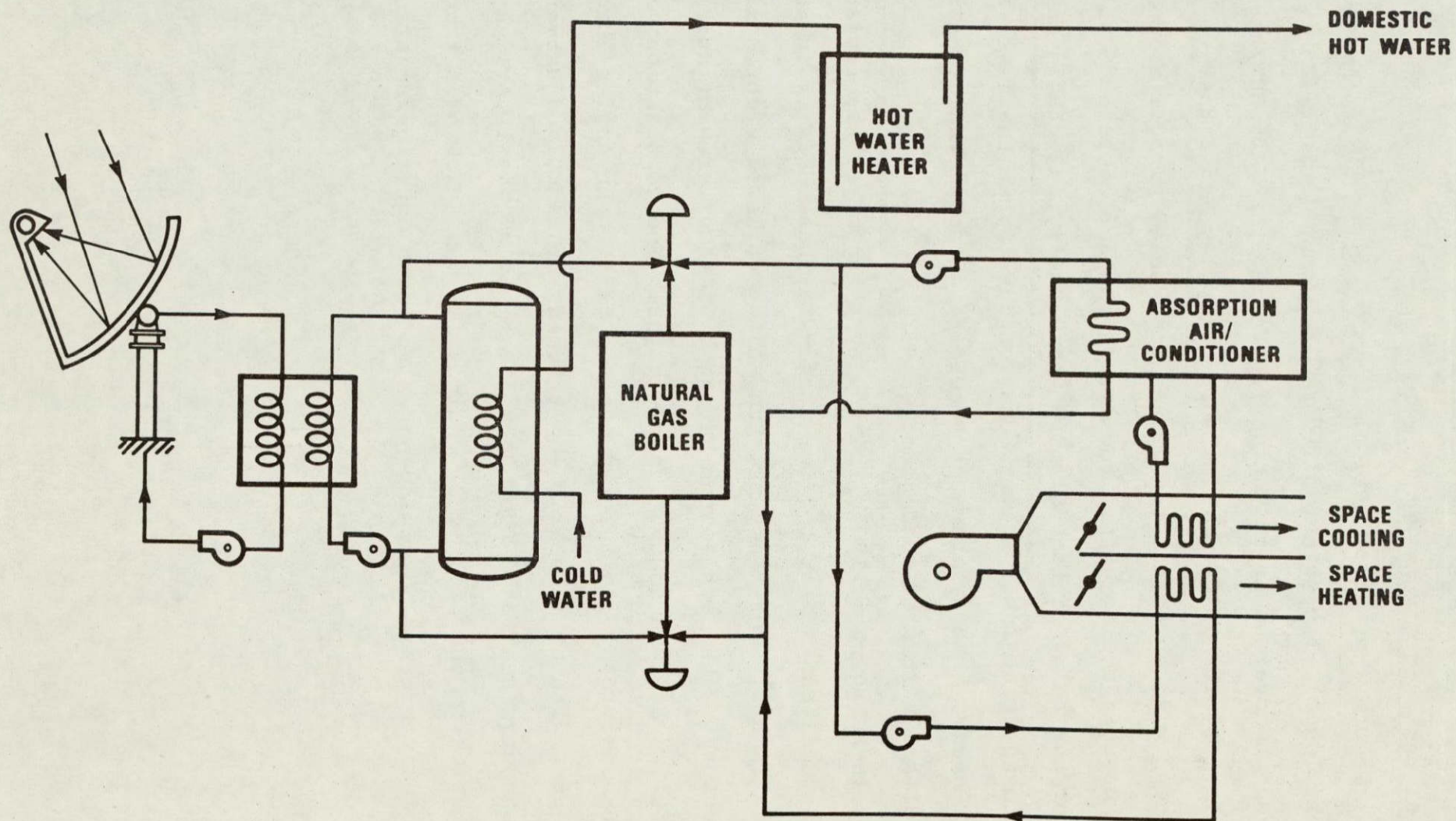


FIGURE 3

1. Solar Collector Loop Pump Control

Figure 4 presents a block diagram of the solar collector loop pump logic. The solar collector loop pump (Pump P-11) is energized whenever solar radiation is greater than 100 BTU/hr-sq.ft. The control system initially included an Eppley Model 8-48 pyranometer with an associated custom engineered circuit to convert the pyranometer analog signal to a relay contact closure. The set point for the relay contact closure was manually adjustable and the relay closed at a higher solar radiation level than the level at which it opens. The pyranometer sensed total solar radiation on a fixed surface tilted at 40 degrees.

In February of 1980, the Eppley pyranometer was replaced by a Honeywell sun sensor for the reasons discussed later in Section VII, Paragraph I. The Honeywell sun sensor utilizes eight silicon photo sensors, with each sensor having a field of view of approximately 30° in azimuth and 50° in elevation. The combination of eight sensors provides complete coverage of all sun angles throughout the year without automatic sun tracking or manual adjustment of sun sensor elevation. The 30° x 50° field of view provides an approximation to the desired 3° conical field of view of a tracking pyrliometer but has no moving parts and does not require tracking mechanisms.

The outputs of all eight sensors are continuously monitored and the maximum level is compared to an adjustable reference voltage. If the maximum sensor level exceeds the manually adjustable threshold level, a time delay relay (TDR-2 on Drawing 95177060 in Appendix C) is energized. TDR-2 energizes the solar collector loop pump relay (R-2) immediately. When a cloud passes over the sun sensor signal will be lost. TDR-2 is an off delay relay that starts a delay period when the signal from the sun sensor is lost. This TDR continues to energize normally open (N.O.) Relay R-2 for 10 minutes after loss of sun signal. The solar collector loop pump therefore continues to operate for this 10 minute period.

SOLAR COLLECTOR LOOP PUMP CONTROL

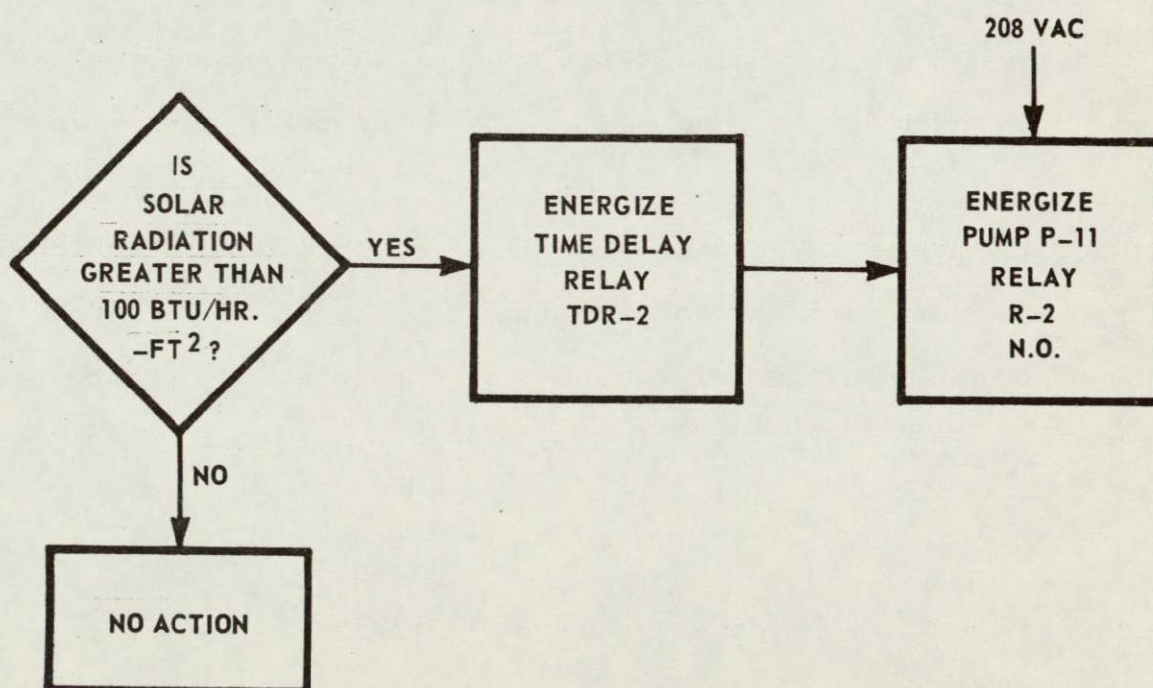


FIGURE 4

2. Solar Collector Master Control

Figure 5 is a block diagram of the solar collector control logic. Several sensors provide information to the solar collector master controller. Depending on this information a series control circuit will (or will not) issue a "track authorize" to the solar collector local controllers. All of the following conditions must be met before a track authorize signal is issued:

- Conventional (not emergency) electric power available.
- Flow in primary loop.
- Storage tank temperature less than 230°F.
- Wind speed below 30 mph.
- Solar radiation above 100 BTU/hr-ft²
- Solar collector loop temperature less than 250°F.
- Authorize signal time delay.
- Solar collector control switch.

The following is a discussion of the rationale and implementation of the conditions required to issue the track authorize signal.

Electric Power Safety - In the event of loss of conventional electric power, a motor generator is automatically started to provide backup power to operate the solar collector controls, to operate

SOLAR COLLECTOR CONTROL

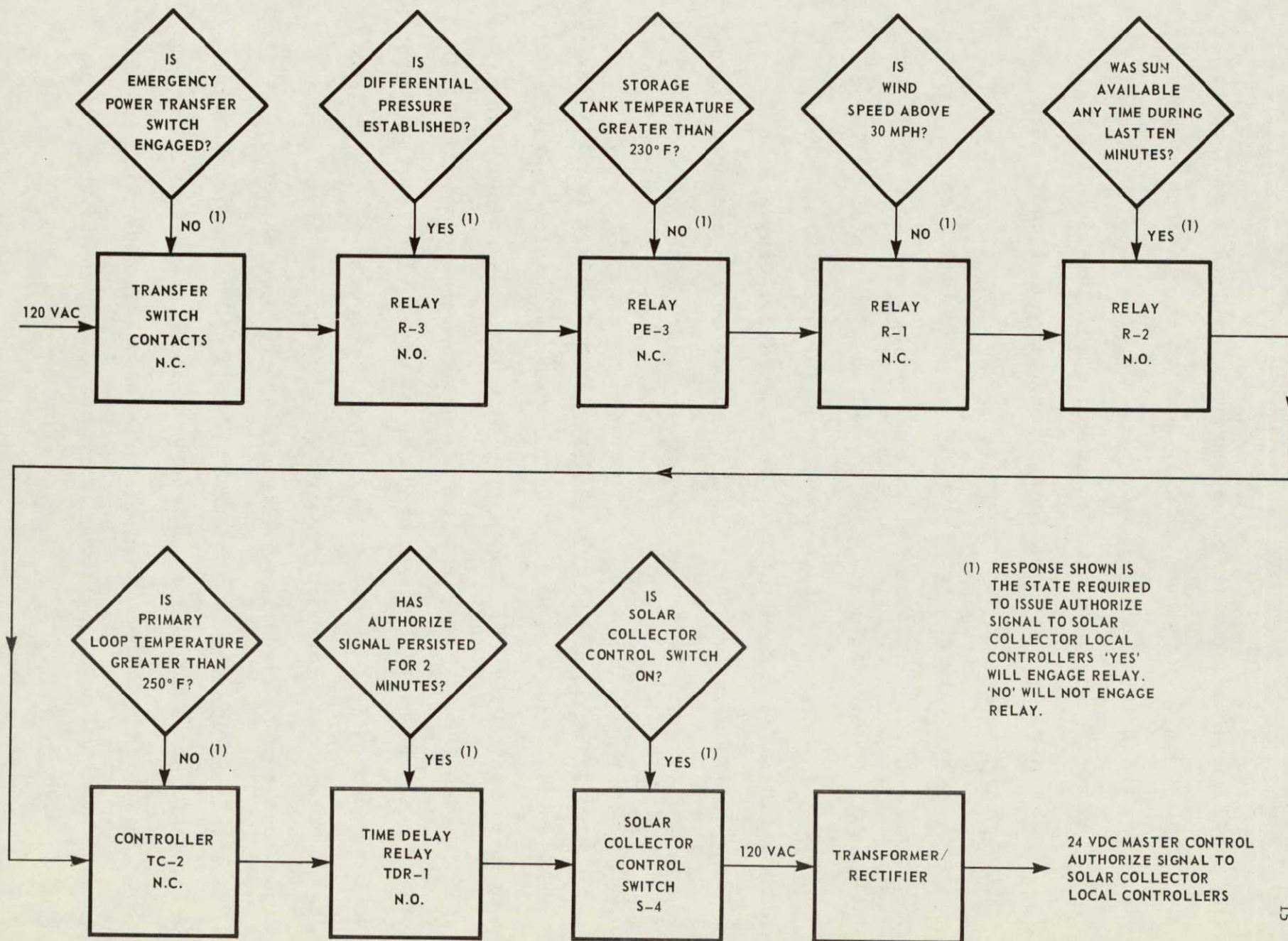


FIGURE 5

the solar collector loop pump, and to drive the solar collectors to the stow position. When there is loss of conventional power, auxiliary contacts in the transfer switch open which removes the 24 VDC authorize signal to the solar collector local controller. The local controllers will sense the loss of signal and return the solar collectors to the stow position.

Solar Collector Loop Flow Safety - The solar collector loop pump control was discussed in the previous section. A differential pressure switch contact is closed when the solar collector loop pump is energized and the pump head is established. This differential pressure switch acts to close N.O. Relay R-3 on Drawing 95177060 in Appendix C. The closure of R-3 contacts is one of the series connected events required to authorize the solar collectors local controllers.

High Tank Temperature Safety - Sensor T-5 on Drawing 95177060 senses storage tank temperature and provides an analog pressure signal to Controller C4. Controller C4 will cause pressure relay PE-3 to open the N.C. contacts of PE-3 at temperatures above 230°F. If the contacts of PE-3 are opened the 24 VDC authorize signal will be removed at all of the solar collector local controllers. These eleven solar collector local controllers will sense this loss of signal and return the solar collectors to the stow position.

High Wind Safety - A Weather Measure Corp. Model Number W-161 wind sensor is used to detect wind speed. When a wind speed above 30 mph (adjustable) is detected, Relay R-1 on Drawing 95177060 is activated and normally closed contacts are opened. The opening

of Relay R-1 contacts will remove the 24 VDC authorize signal to the solar collector local controllers. The local controllers will sense this loss of signal and return the solar collectors to the stow position.

Solar Radiation Sensor - The solar radiation sensor and control logic was discussed in the Solar Collector Loop Pump Control Section. When the solar radiation sensor level exceeds a manually adjustable threshold level, a time delay relay (TDR-2 on Drawing 95177060) is energized. TDR-2 energizes N.O. Relay R-2 immediately. When a cloud passes over and the sun sensor level drops below the threshold setting, TDR-2 starts a 10 minute delay period. TDR-2 continues to energize N.O. Relay R-2 for this 10 minute period. If the sun does not return during the 10 minute delay, the solar collector 24 VDC authorize signal will be removed and the solar collectors will return to stow. TDR-2 only delays solar collector return to stow in the event of loss of sun. Return of solar collectors to stow for any other reason except loss of sun is not delayed by TDR-2. The solar radiation controller is currently set to close Relay R-2 when solar radiation is above 100 BTU/hr-ft^2 .

Solar Collector Loop High Temperature Safety - A Honeywell temperature sensor (Sensor T-4 on Drawing 95177060) senses the solar collector outlet temperature. If the solar collector outlet temperature exceeds 250°F , controller TC-2 opens normally closed (N.C.) contacts. The opening of these contacts will remove the 24 VDC authorize signal to the solar collectors. The local controllers will sense this loss of signal and return the solar collectors to the stow position.

Authorize Signal Time Delay - A time delay relay, TDR-1, is included in the collector authorize signal series circuit to prevent short cycling of the solar collector drive motors. TDR-1 is an "on delay" relay. When the solar collector authorize signal is removed (even for an instant), TDR-1 does not allow the authorize signal to be reissued for 2 minutes (adjustable). The collector authorize signal must persist for 2 minutes before the authorize signal is issued to the solar collector local controllers.

Solar Collector Control Switch - A manual control switch, Switch S-4 on Drawing 95177060 Sheet 2, is included in the solar collector authorize signal series circuit. Switch S-4 allows an operator to manually return all collectors to the stow position for maintenance, etc.

3. Solar Collector Local Control

The solar collector local control includes a Honeywell Flux Line Sun Tracker (FLST), a microprocessor based controller. The FLST consists of two primary parts, the sensor head and the electronic controller. The sensor head is mounted to the absorber tube housing and contains sensors positioned on each side of the absorber tube.

The Flux Line Sun Tracker Control System operates in two primary modes.

- Acquisition
- Tracking

During the acquisition mode, the microprocessor continuously scans the track authorize discrete input port. When wake-up authorization is sensed, the drive motor electronics are activated to drive the collector forward. The flux sensors in the sensor head are

continuously scanned. When flux of about 3X concentration is sensed on one of the sensors, the collector is then incremented until the flux beam is centered on the receiver tube and the sensors are balanced. The flux line sun tracker acquisition mode is then changed to the tracking mode. During the tracking mode, concentrated solar flux reflected from the solar reflector panels is focused between the sensors and on the absorber tube. The electronic controller operates the solar collector panel drive motor forward or backwards as required to keep the flux line between the sensors.

Sensor placement and drive time are the only adjustments necessary during installation for proper collector tracking. Internal control damping is used to delay control due to wind gusts, spurious solar reflections, etc. This damping feature prevents oscillations and excessive cycling. If the sun goes behind a cloud for 30 minutes, the controller initiates a search scan once every 10 minutes to reestablish solar lock-on. If the track authorize signal is removed, the collectors are stowed.

4. Solar Heat Exchange Bypass Control

The Dowtherm SR-1 and water heat transfer fluid in the solar collector loop will cool to approximately outdoor ambient temperature during overnight periods. During the winter months in Columbus, Ohio, this will often be below the freezing point of water. For solar system start-up at low temperature the solar collector loop fluid is bypassed around the solar heat exchanger. This prevents very cold Dowtherm SR-1 (which at start-up has not been heated in the solar collectors) from entering the primary side of the solar heat exchanger and freezing the water on the secondary side of the heat exchanger. This heat exchanger bypass control is shown in Figure 6.

SOLAR HEAT EXCHANGER BYPASS CONTROL

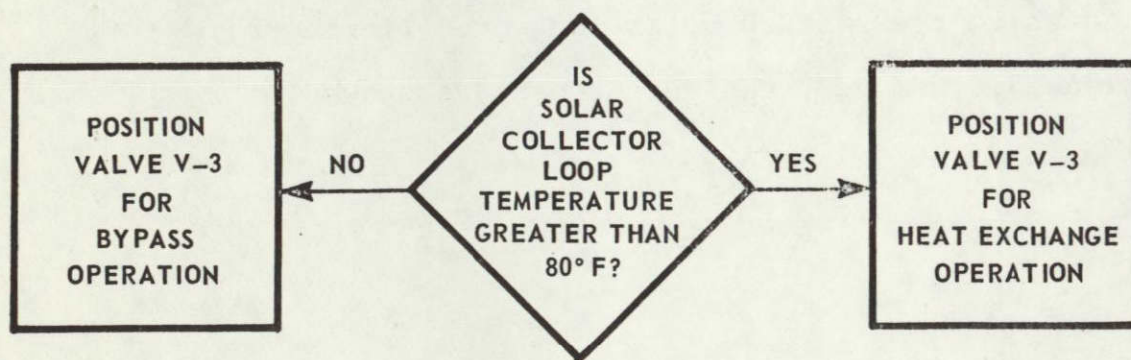


FIGURE 6

5. Solar Storage Loop Pump Control

Rust inhibited water is pumped through the secondary side of the solar heat exchanger to the building heating/cooling system and/or to solar storage by the solar storage loop pump (Pump P-10). The solar storage loop pump is only operated when the primary loop pump (Pump P-11) is energized and when the solar collector loop temperature is 10°F higher than the solar storage tank temperature. A solar storage loop pump control block diagram is shown in Figure 7.

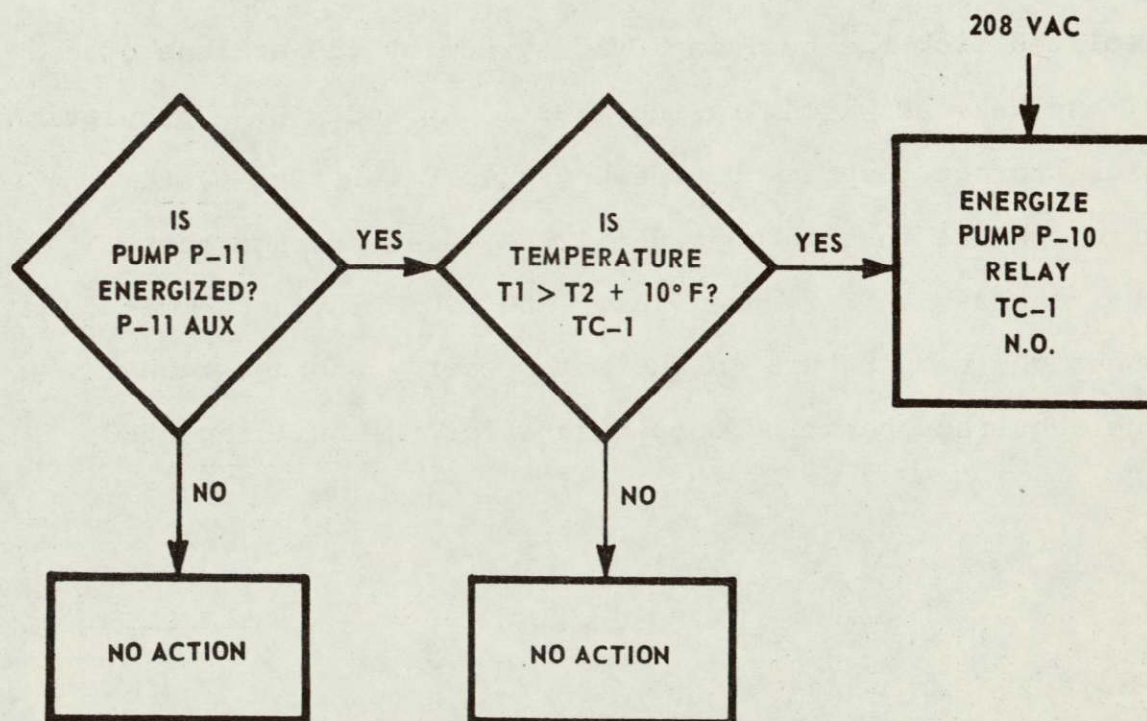


FIGURE 7

6. Solar Energy/Natural Gas Switchover Control

The Solar Energy/Natural Gas Switchover Control is designed to operate the Highlights Building Heating and Cooling system entirely on solar energy when the storage tank temperature is above 140°F in the winter and 190°F in the summer. The building space heating system requires 140°F hot water and the absorption chiller used for space cooling during the summer requires 190°F hot water.

When the temperature in the solar energy storage tank is below the temperature required for the building HVAC system (140°F winter/190°F summer) all solar energy collected by the solar collector loop is delivered through the solar heat exchanger to the 5,000 gallon thermal storage tank. The solar energy storage loop is isolated from the building HVAC system by the actions of valves V-1 and V-2, shown on Drawing ME-2 in Appendix E. Circulation in the solar storage loop is provided by pump P-10. The system continues to operate in this mode until the solar storage tank temperature reaches 140°F in the winter and 190°F in the summer.

When the temperature in the solar energy storage tank exceeds the required operating temperature for the building HVAC

system (140°F winter/190°F summer) gas supply to the HVAC system boiler is interrupted and valves V-1 and V-2 are repositioned to permit flow from both the solar energy storage tank and from the solar collector loop to be delivered to the HVAC system. This mode of operation continues until the temperature of the hot water delivered by the solar energy system to the HVAC system has dropped below 183°F during cooling operation or 130°F during space heating operation. The control system then returns the building HVAC system load to the natural gas boiler until the hot water temperature available from the solar system is again adequate to carry the building load. A block diagram of the solar energy/natural gas switchover control is presented in Figure 8.

The solar energy system can supply energy from the thermal storage tank to the building HVAC loads during periods when there is no solar energy available to be collected if the temperature in the thermal storage tank exceeds the minimum operating temperatures required by the building HVAC system (140°F for space heating and 190°F for space cooling). In this mode, when the building HVAC system controls call for heating or cooling operation energy is withdrawn first from the solar energy storage tank rather than from the natural gas boiler. Solar energy is used until the delivered water temperature from the solar energy storage tank drops below the minimum temperatures required by the HVAC system. The controls then switch the HVAC loads from the solar energy system to the natural gas boiler.

The control system drawings for the Highlights Building solar energy system are contained in Appendix C.

SOLAR ENERGY/NATURAL GAS SWITCHOVER CONTROL

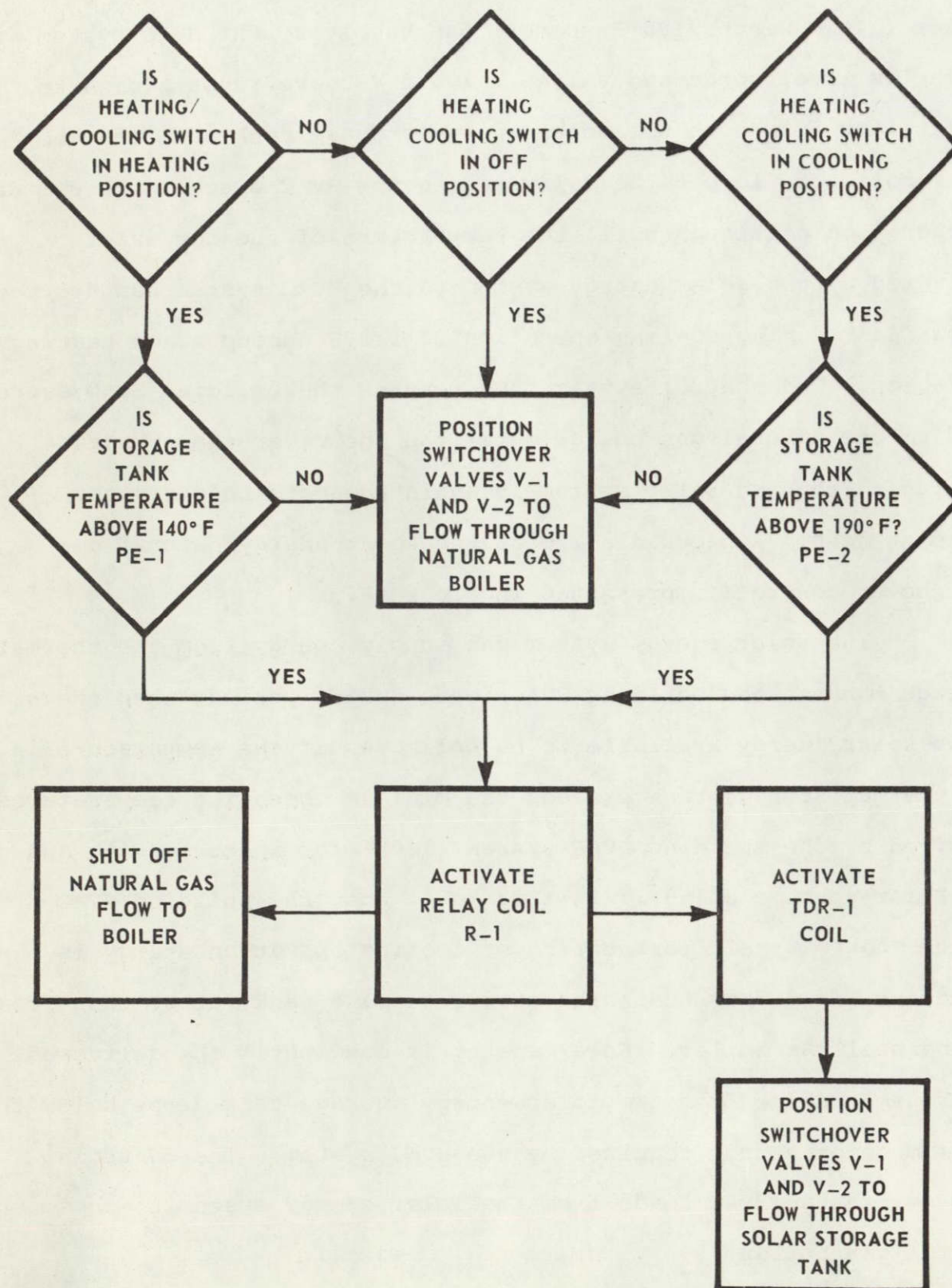


FIGURE 8

7. Domestic Hot Water Solar Preheat

All city water used to supply domestic hot water in the Highlights Building passes through an immersion coil heat exchanger in the solar energy storage tank. Stored solar energy is automatically used to preheat this city water whenever the temperature in the storage tank exceeds the city water temperature. The degree of preheat provided to the domestic water is a function of the hot water flow rate and the temperature in the solar storage tank.

C. Solar Collectors

The solar collector field at the Highlights Building consists of 2,978 ft² of Honeywell single axis tracking, concentrating solar collectors. The collector field is arranged in 11 east-west oriented rows with four collector panels per row. Each solar collector row operates independently under the control of an individual local controller and sun tracking system. Figure 9 is an aerial view of the solar collector field on the roof of the Highlights Building.

The Honeywell solar collector includes a half parabolic reflector that has a 50.76" aperture. The half parabolic reflector has a 20 mil aluminum skin adhesive-bonded to each side of an expanded aluminum honeycomb core. The edges of the honeycomb panel are closed with extruded vinyl channel sections mounted with epoxy and sealed with silicon rubber caulk. The half parabolic reflector panels were fabricated for Honeywell by Hexcel Corporation, a manufacturer of aluminum honeycomb products. The focal length of the reflector panel is 36 inches and the rim angle is 72°.

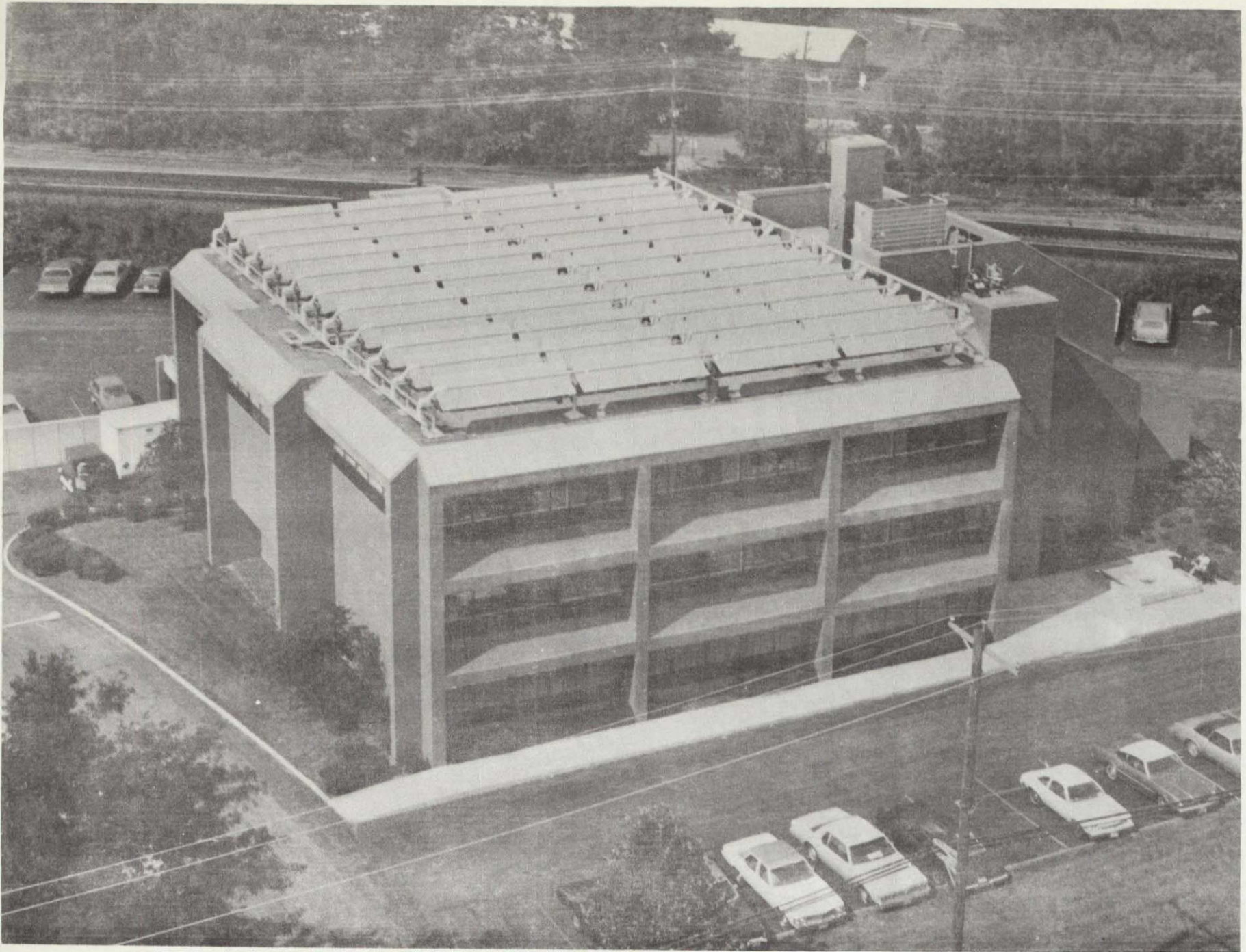


Figure 9

A reflective film was applied by Hexcel Corporation to the concave side of all reflector panels. The reflective film is FEK244, a back aluminized self-adhesive acrylic film manufactured by 3M Corporation. Specular reflectivity of this film is nominally 83 percent when first installed.

Each 16 foot long reflector panel is reinforced with four expanded aluminum honeycomb strongback supports which maintain the reflector curvature and provide structural support for the arms which mount the absorber housing. These structural supports were adhesive-bonded and mechanically fastened with sheet metal screws to the back side of the reflector panel by Honeywell. As shown in Figure 10, the strongback supports are riveted to 4" x 4" structural steel tubing which is the primary torsional load bearing member of the collector panel.

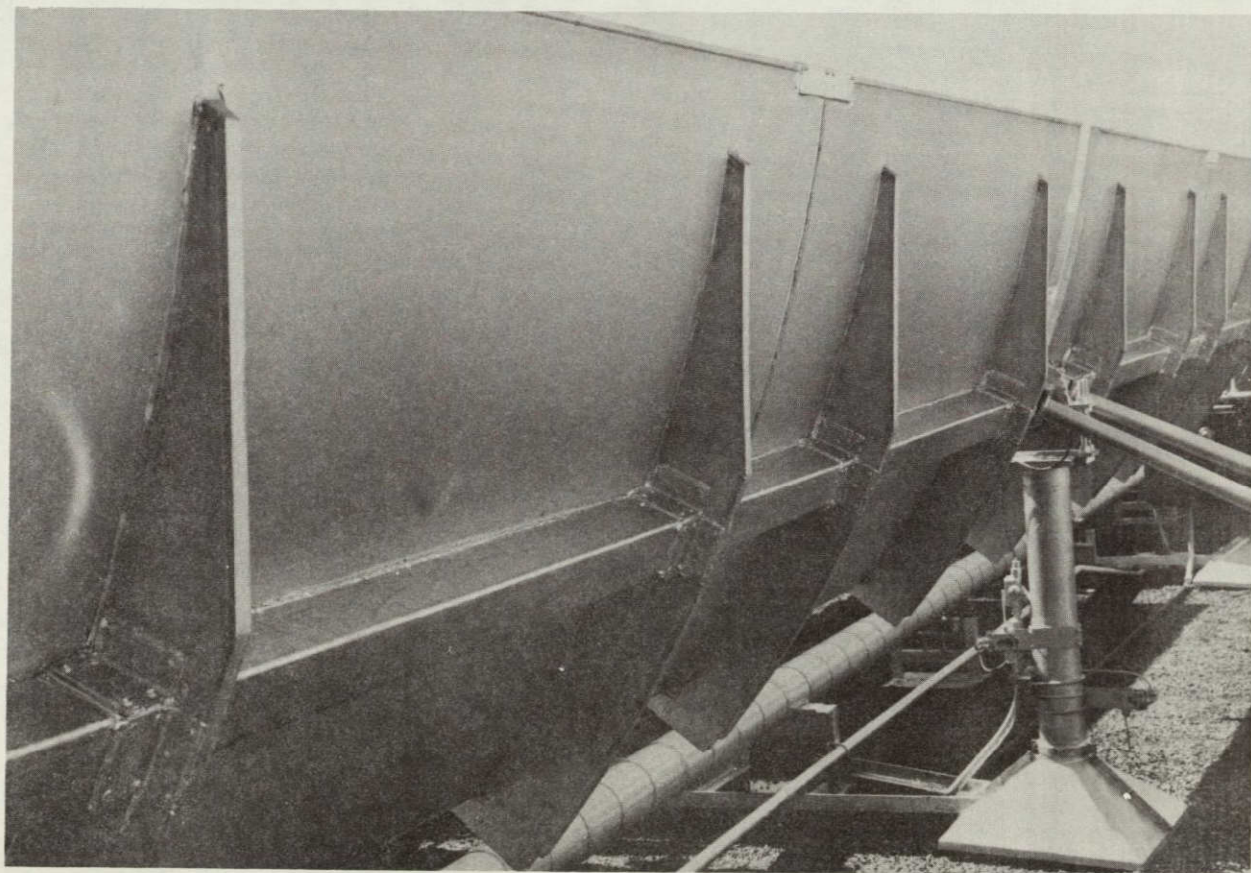


Figure 10

The ends of the solar collector panels, except at the center drive pylon, are supported by 1-3/4 inch babbitt Link Belt bearings. Height and positional alignment of the bearing mounting plates is accomplished with an adjustable four bolt assembly. The connection and alignment of adjacent solar collector panels is accomplished with mating flanges. These mounting details are shown on Figure 11.

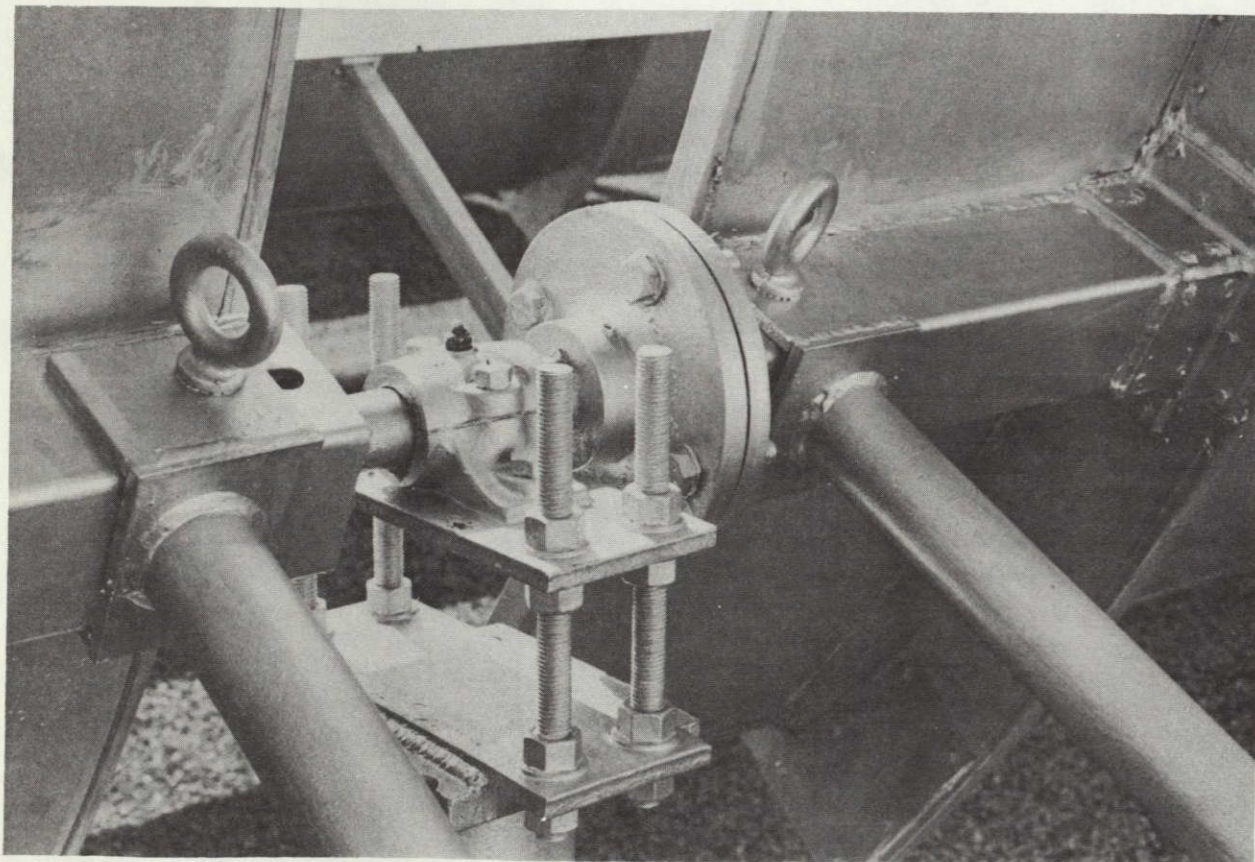


Figure 11

Solar energy is reflected from the solar panel onto a 1-1/4" outside diameter steel tube. This absorber tube is selectively coated with Harshaw black chrome over bright nickel electroplated by Honeywell. Solar spectrum absorptivity as applied was 95%. Infrared emissivity was 12%. The selectively coated tube is mounted at the focal point of the half parabola.

The back side of the absorber tube is enclosed and insulated with an extruded aluminum housing containing preformed THERMO-12, a hydrous calcium silicate insulation manufactured by Johns-Manville. The concentrated solar radiation from the reflector passes through a single thickness of etched low iron glass which closes the absorber housing. Non-specular aluminum reflectors are mounted on both sides of the absorber tube to reflect scattered radiation onto the absorber tube. Figure 12 is a line drawing of the Honeywell collector.

PARABOLIC CONCENTRATING COLLECTOR

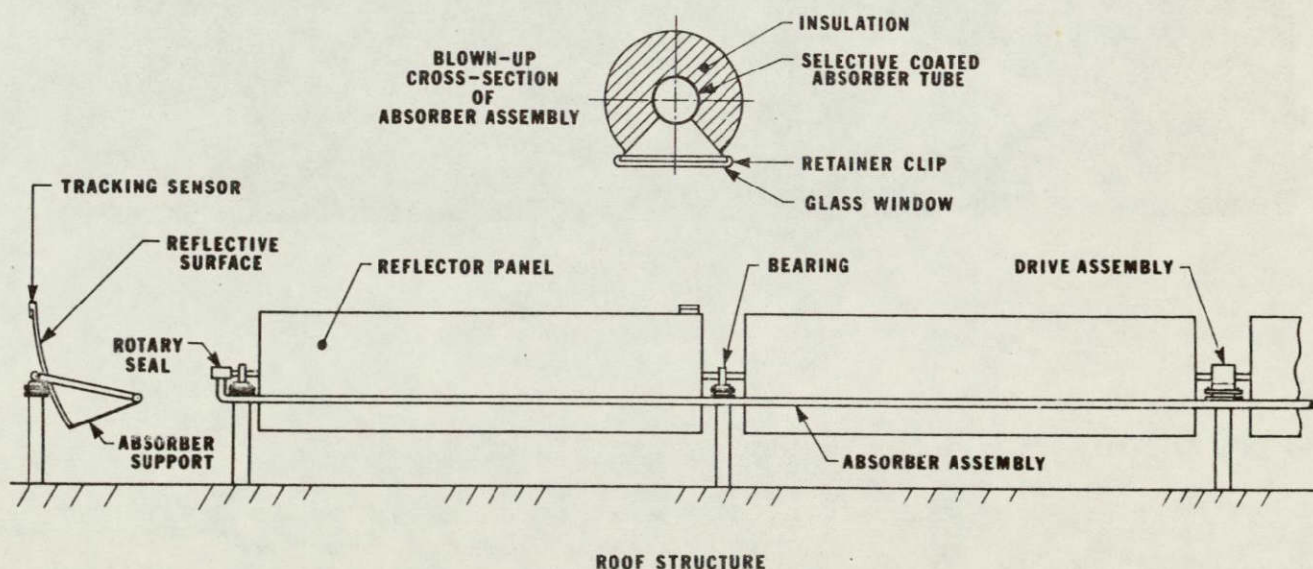


Figure 12

Each solar collector row has a drive system which consists of a DEMAG cone brake motor, flange-mounted on a Winsmith 5000:1 speed reducer, as shown in Figure 13. Technical specifications on the solar collector drive system components are included in Appendix D. This drive system is capable of rotating the collector panels from the stow position to the nominal tracking position in 90 seconds.

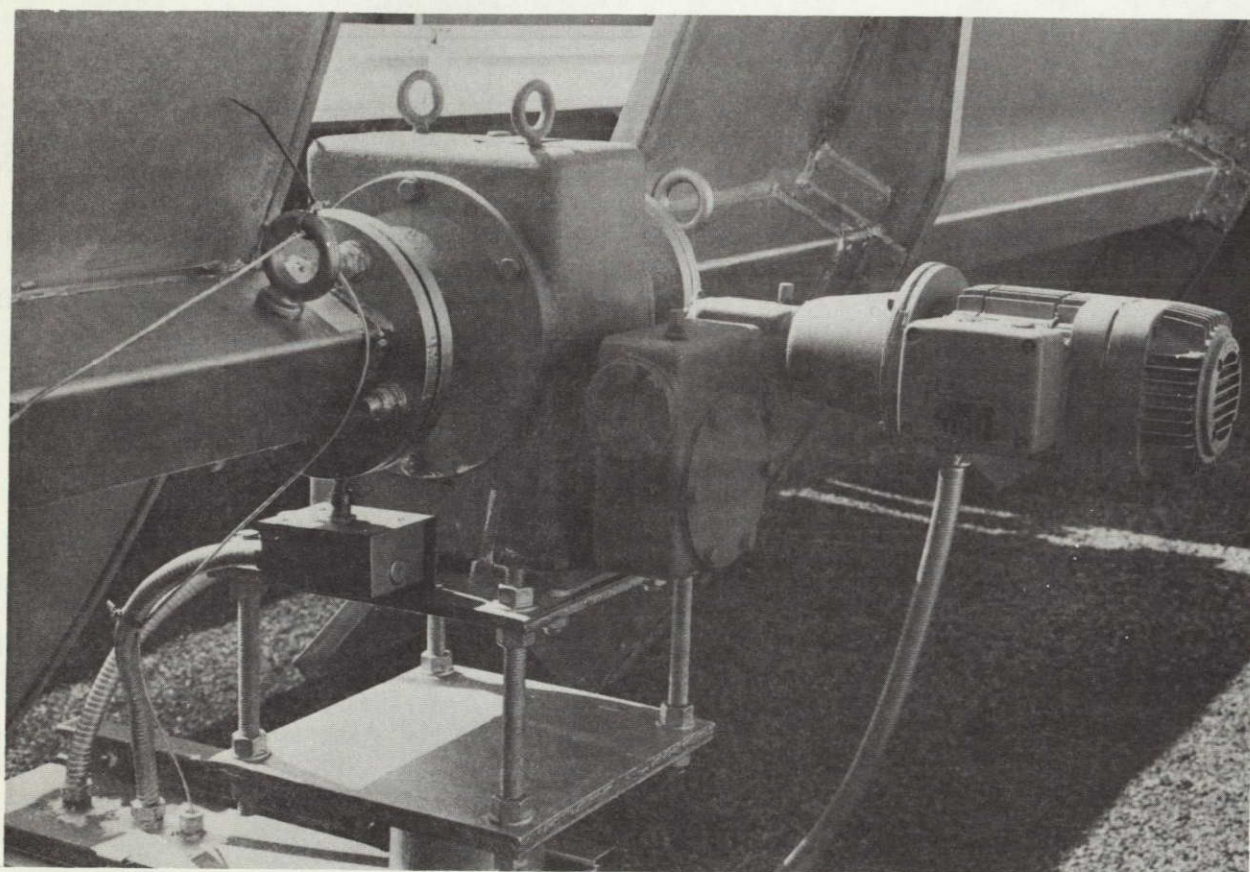


Figure 13

D. Solar Collector Loop Heat Transfer Fluid

The solar collector loop heat transfer fluid is a freeze protected solution of 44% by volume Dowtherm SR-1 (ethylene glycol) and 56% by volume water. The solar collector loop is provided

with manual fluid makeup to assure consistent concentration of the anti-freeze in the heat transfer fluid. The solar collector loop is monitored for corrosion by a prototype automatic corrosion monitoring system being field tested in cooperation with Argonne National Laboratories and Texas Instruments.

E. Solar Heat Exchanger

Heat is exchanged between the solar collector fluid loop and the storage loop in a Bell & Gossett shell and tube heat exchanger, Model Number OF 1011-14, located in the equipment room on the ground floor of the Highlights Building. The heat exchanger has an effectiveness of 60% at design conditions. Technical specifications for the heat exchanger are included in Appendix D.

F. Solar Collector Loop Pump

The solar collector loop pump (P-11) is a 75 gpm Thrush pump, Model Number 2-TV-2, located in the ground floor equipment room of the Highlights Building and immediately adjacent to the solar heat exchanger.

Expansion in the solar collector loop is provided by a 120 gallon Bell & Gossett expansion tank mounted in the penthouse at the top of the mechanical corridor at roof level.

G. Thermal Energy Storage Tank and Enclosure

Storage energy storage in the Highlights Building system is provided by a 5,000 gallon capacity, low profile ASME pressurized storage vessel produced by the Adamson Tank Company. Expansion in the storage loop is provided by a 529 gallon Adamson expansion

tank located immediately adjacent to the storage tank. The storage tank and expansion tank are located in a building addition constructed 4' below grade level on the east wall of the Highlights Building. Addition of this structure was required because there is no space available in the Highlights Building equipment room for a large solar energy storage tank, and because the Highlights Building is constructed on a limestone and shale outcropping which would have made burial of the storage tank prohibitive.

H. Storage Loop Pump

The storage loop pump (P-10) is a 95 gpm Thrush pump, Model 2-TV-2, located in the equipment room immediately adjacent to the solar heat exchanger.

I. Domestic Hot Water Preheat System

All city water flowing to the domestic hot water system in the Highlights Building passes through a Bell & Gossett immersion tank heater, Model Number TCW-696, mounted through the upper side-wall of the solar energy storage tank. The temperature of the preheated water delivered to the natural gas fired storage water heater is a function of domestic water flow rate and the solar storage tank temperature. The natural gas-fired storage water heater is maintained at a minimum tank temperature of 140°F. The system is provided with a Hydroguard water mixer which automatically blends cold city water with hot water from the domestic storage water heater prior to delivery if the solar preheated water in the domestic storage water heater exceeds the desired hot water delivery temperature.

J. Emergency Power System

The Highlights Building solar energy system includes an emergency generator to drive the collectors to the stowed position in the event of a power failure. An Onan 30 kW (37.5 KVA) three-phase AC generator set, Model Number 30.0 EK-15R, interfaces with the building electrical system through an Onan automatic transfer switch. The generator and transfer switch are shown in Figure 14.

The automatic transfer switch automatically starts the standby generating set on interruption of normal power and transfers the load circuits when the set reaches proper speed and voltage. When normal power resumes, the automatic transfer switch retransfers the load to the line and stops the generating set. The power source being connected to the load supplies the switching power.

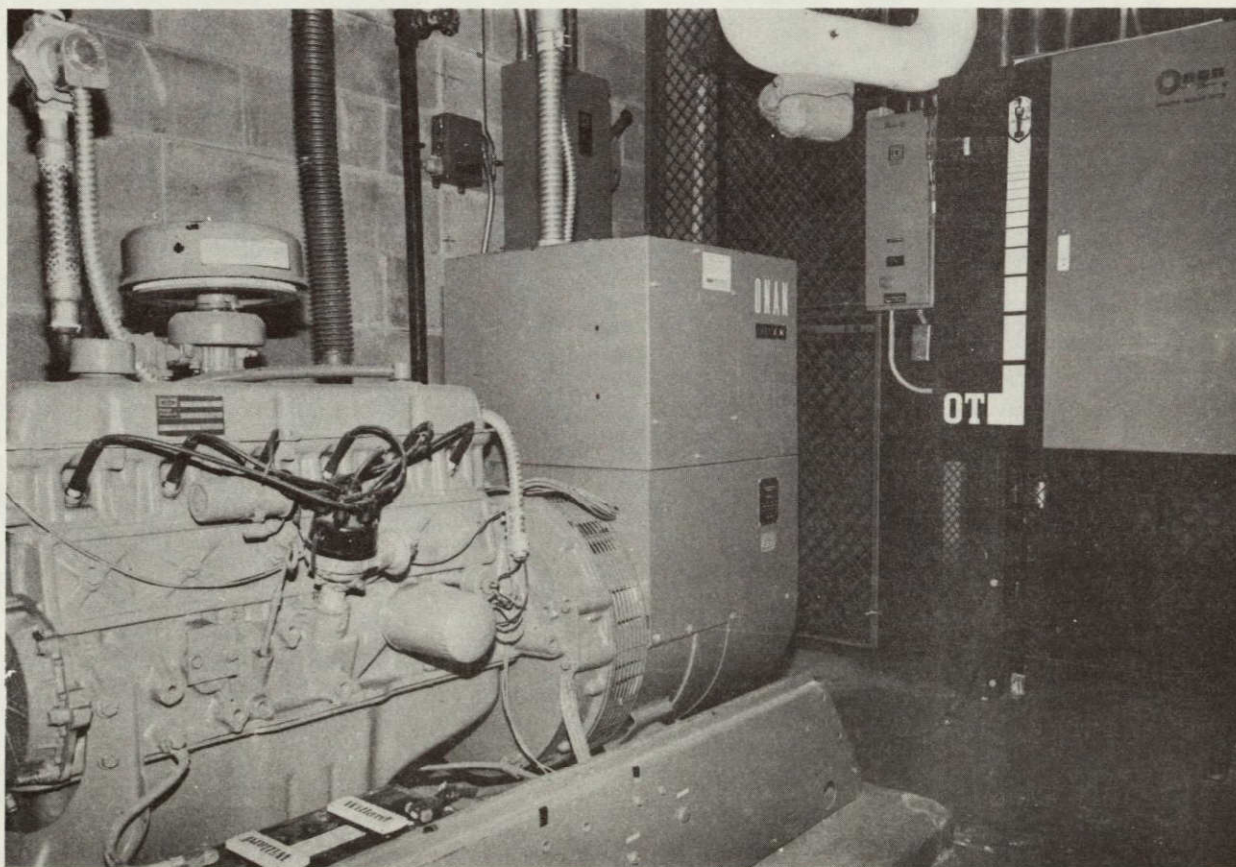


Figure 14

ORIGINAL PAGE IS
OF POOR QUALITY

V. SOLAR ENERGY SYSTEM INSTALLATION

The Highlights Building solar energy system installation was jointly funded by the U.S. Department of Energy and the Columbia Gas System Service Corporation under Agreement Number EG-77-A-01-4089. Columbia functioned as the prime contractor for the installation.

A. Consulting Engineer

On-site supervision of construction was provided by:

H. A. Williams and Associates, Inc.
980 West Henderson Road
Columbus, Ohio 43220

B. Construction Subcontractors

Columbia's construction subcontractors were:

Mechanical:	Sauer, Inc. 747 Chambers Road Columbus, Ohio 43212
Electrical:	Burroughs-Hatfield Electrical Co. 527 East Hudson Columbus, Ohio 43202
General:	J. P. O'Connor Company 659 North Fourth Street Columbus, Ohio 43215
Controls:	Honeywell, Inc. 1320 Dublin Road Columbus, Ohio 43215
Steel Fabrication:	J. T. Edwards Company 1241 McKinley Avenue Columbus, Ohio 43222
Sheet Metal:	Martina Metal Contracting Company 1575 Shawnee Avenue Columbus, Ohio 43211
Insulation:	Earl Bright & Company 970 Higgs Avenue Columbus, Ohio 43212

C. Construction Schedule

The actual construction schedule for installation of the solar energy system in the Highlights Building is shown in Table 2. Columbia experienced significant schedule delays due to winter weather and delays in delivery of the solar collectors and the storage vessel. Construction of the solar energy system and installation of the government data acquisition system were completed in July, 1978. The government SDAS was placed in operation in early August, 1978.

D. Construction Problems and Resolution

Several problems arose before and during installation of the solar energy system. The following identifies the major problems and the corrective action taken.

1. Solar Collector Absorber Tube Interference

The Highlights Building solar energy system was designed during the third and fourth quarters of 1976, and was proposed to U.S. DOE under PON - Cycle 2 for commercial buildings in November, 1976. Columbia's technical proposal described a 3324 sq. ft. solar collector field consisting of 12 rows of Honeywell single axis tracking, concentrating solar collectors.

During the period when DOE was evaluating the technical and cost proposals submitted in response to the PON - Cycle 2 solicitation, Honeywell finalized the design of their solar collector for the Columbia installation and similar installations at Honeywell's General Office Building in Minneapolis, Minnesota

CONSTRUCTION, INSTRUMENTATION AND EVALUATION SCHEDULE

<u>Milestone</u>	<u>Original Schedule</u>	<u>Actual Completion</u>
Initial Design Review	Sept. 20, 1977	Oct. 4, 1977
Final Design Review	Oct. 14, 1977	Nov. 15, 1977
Start Solar System Installation	Oct. 17, 1977	Oct. 17, 1977
Solar Collector Delivery	Nov. 1, 1977	Jan. 16, 1978
Complete Major Component Delivery	Nov. 1, 1977	April 18, 1978
Complete Sensor Delivery	Jan. 2, 1978	June 15, 1978
Site Data Acquisition System Delivery	Feb. 1, 1978	Jan. 25, 1978
Complete Solar System Installation	Feb. 15, 1978	July 12, 1978
Complete Instrumentation Installation	March 1, 1978	July 26, 1978
Begin Operation of Site Data Acquisition System	-	Aug. 10, 1978
Complete Acceptance Testing	July 1, 1978	May 16, 1979
Open House Ceremonies	July 15, 1978	Dec. 6, 1978
End of Demonstration Period	July 1, 1983	May 16, 1984

TABLE 2

and a Westpoint Pepperell fabric mill at Fairfax, Alabama. In August, 1977, Honeywell informed Columbia that they had changed the parabolic shape and the focal length of the reflector, which resulted in an increase of 4 inches in the swing radius. This change would have caused interference between the absorber housings of adjacent rows in certain rotational modes, which could have resulted in damage to the collectors.

Columbia and H. A. Williams identified two potential solutions to this interference problem.

- Design and install a system to control the rotation of collectors to assure that the absorber housings of adjacent rows could not both be in the interference region at the same time.
- Redesign the solar collector field and increase the row-to-row spacing to eliminate the interference between adjacent rows. This change required reducing the number of solar collector rows from twelve to eleven.

Columbia elected, with DOE approval, to eliminate one row of collectors from the solar collector field rather than to design an interference prevention system.

2. Solar Collector Drive Change

In August, 1977, Honeywell also changed the solar collector gear reducer/drive motor design. The original design included a gear reducer/drive motor for each pair of solar collector panels. The new design has four solar collector panels driven by a single gear reducer/drive motor. This design change, which occurred after construction drawings were completed and construction bids

were finalized, required a relayout of the solar collector support posts, most of the solar collector loop plumbing and the solar collector drive motor wiring.

3. Solar Collector Panel Edge Sealing

The Hexcel reflector panels used in the Honeywell solar collector were equipped with extruded plastic edge caps to prevent water from entering the honeycomb panel. These end caps were attached to the reflectors with epoxy, but were not waterproofed with a resilient caulk between the plastic cap and the surfaces of the reflector panel. Honeywell identified this deficiency after the solar collectors were delivered to Columbia. The solar collectors were moved from the construction site to the pilot plant of Columbia's research facility, uncrated, sealed with silicon rubber caulk, reboxed and redelivered to the building site.

4. Storage Tank Foundation

For the reasons discussed in Section IV, Paragraph G, the site selected for the 5000 gallon solar energy storage tank was adjacent to the east side of the Highlights Building (see Drawings G-1 and G-2 in Appendix E). Excavations performed at the site indicated that loose fill was present in the storage tank footing areas. In order to properly support the weight of the storage tank and to prevent damage to concrete encased telephone conduits located in the area, excavation was continued to a depth where solid bearing material appeared. Excavation was required to a depth approximately 3-1/2 feet below the finished floor.

elevation. The foundation volume below the 6 inch, 4000 psi concrete floor slab was filled with K-CRETE, a low density, 2000 psi concrete.

5. Solar Collector Panel/Support Post Interference

Honeywell was not in a position to supply detailed shop drawings of the solar collector, which would have permitted support system design by Columbia and H. A. Williams and Associates. Therefore, Honeywell designed the support posts to support the solar collector system and established the post-to-post spacing required for proper collector mounting. J. T. Edwards and Company fabricated the support posts to the Honeywell design and they were installed by Sauer, Inc. to the Honeywell specifications. Sauer identified an error in the Honeywell design when they attempted to mount the first collector panels between the support posts. The solar collector panels would not fit between the post caps of the collector mounting system.

Columbia and H. A. Williams identified a solution to this problem which required field cutting of the lateral post cap protrusions into the space between the posts, and field welding of new post caps with increased extension perpendicular to the collector row to permit mounting of the adjustable bearing mounting plates.

6. Solar Collector Panel/Local Controller Interference

The Honeywell local controller box for each solar collector row was designed to be mounted to the center support post of each row parallel to the axis of rotation of the solar collector row. Columbia identified potential interference between the local

controller box and the solar collector panel when the panel was rotated. The local controller box mounting was modified to allow mounting the local controller perpendicular to the solar collector axis of rotation. This eliminated the interference problem.

7. HVAC Duct Interference

The solar collector mounting posts were designed to be fastened to the roof of the building with bolts that extended through the roof. At several solar collector post locations there was building heating and air conditioning duct work immediately below the roof. The insulated HVAC ductwork had to be removed in order to gain access to the underside of the roof in these locations. After the solar collector support posts were bolted in place the HVAC ductwork was replaced.

8. Speed Reducer/Motor Drive Revisions

Numerous rework operations were required to properly mount the solar collector electric drive motor on the speed reducer. The speed reducer to motor adapter plate supplied by Honeywell was made incorrectly and had to be remachined by Columbia. The key supplied for the metric Demag motor keyway did not fit and had to be ground. The speed reducer to motor flexible coupling did not fit the motor and had to be machined. Honeywell had no provision in the design to prevent the flexible coupling from sliding along the shaft and contacting the cone flange motor mount. Columbia added set screws to the couplings as required to solve this problem.

9. Absorber Tube Welding Problems

Considerable difficulty was encountered in field Heliarc welding the 0.090 inch wall hydraulic tubing used for the absorber tube. Windy conditions on top of the Highlights three story office building in April and May of 1978 posed great difficulties to maintaining the inert gas shield surrounding the Heliarc weld zone. A welding tent had to be improvised in order to shield the welding from the wind. This tent had to be moved throughout the solar collector array to the fifty-five absorber tube welding locations. Additionally, the ends of the absorber tubes were beveled, rough and not cut off squarely. This posed very difficult problems for the welder attempting to butt weld in the field. Numerous absorber tube butt welds had tiny pin holes that could only be found during high pressure leak testing of the solar collector loop. These butt welds had to be rewelded which required several drain downs of the system, refills and repressurization to check for leaks.

It is also speculated that the electroplated selective coatings applied to the absorber tube may have contaminated the hydraulic steel tubing weldment and contributed to the weld porosity problem. No laboratory analysis was undertaken to substantiate this theory.

Arc welding of the schedule 40 pipe throughout the remainder of the solar system and the HVAC plumbing system posed no problem for the mechanical contractor.

VI. Solar System Acceptance Testing

Acceptance testing of the Highlights Building solar energy system was conducted in August 1978. Key tests were performed in the presence of the DOE Contracting Officers Representative. The most important deviation from system design identified during acceptance testing was incorrect operating temperatures of the individual high temperature limit switches for each of the solar collector rows. These high temperature limit switches were operating at temperatures approximately 100°F higher than called for in the construction specifications. The switches were replaced by the Honeywell Controls Division.

During acceptance testing it was determined that focused sun light reflected from the solar panel would burn the absorber tube insulation under certain conditions. Each 16 foot long half-parabolic reflector panel has a 16 foot long section of active solar absorber tube. The piping at both the inlet (west end) and outlet (east end) of each 16 foot long section of active absorber tube is covered with Armaflex insulation. Due to the off perpendicular incident angle of the sun's rays with all sun hours before noon, the half-parabolic solar reflector panels focus high concentrations of solar flux on the Armaflex insulation that is immediately to the west of the active area of the solar absorber tube. Similarly, with all sun hours after solar noon, the half-parabolic solar reflector panels focus high concentrations of solar flux on the Armaflex insulation that is immediately to the east of the active area of the solar absorber tube. The Armaflex insulation cannot withstand the

high surface temperatures that result from the high concentrations of solar flux. Therefore, aluminum sheet metal shields were fabricated and installed over the Armaflex insulation in areas adjacent to the active area of the solar absorber. The aluminum sheet metal shields were installed with a controlled air gap between the shield and the Armaflex insulation.

During acceptance testing an override switch was installed on the field controls that will allow an operator to electrically control all of the solar collector motor drive assemblies on days when there is no sun. This override switch allows operation of the solar collectors for maintenance, repair or demonstration on cloudy days.

The maximum rotational angle for each solar collector row is controlled by a roller plunger microswitch that contacts a cam lobe on a cam surface on the speed reducer flange for that row. As a solar reflector panel approaches the maximum rotational angle the roller plunger microswitch will roll up the cam lobe of the cam surface and the control logic will return that row to the stow position. During acceptance testing it was determined that by the middle of November some of the solar collector rows had already reached the maximum rotation angle and the control logic was returning these rows to the stow position. New cam surfaces were fabricated with a profile that will allow all rows to rotate about 5 more degrees and to track the sun down to the lowest point in the sky on December 22nd. These new cam surfaces were installed and aligned with the roller plunger microswitches.

During acceptance testing a problem was encountered with the lubrication oil in the Winsmith three stage helical speed reducers. The speed reducers were supplied with 90W oil which becomes very viscous at low temperatures. At temperatures below 30°F the drive motor could not turn the speed reducer because of the high internal drag. Columbia drained and refilled the eleven Winsmith gear reducers in the Highlights Building solar energy system with 80W oil which allows operation of the speed reducers down to -10°F.

During acceptance testing it was necessary to install a sheet metal pan and drain under the new solar collector loop fluid lines that pass over the elevator controls. New building codes in Franklin County, State of Ohio required this change.

Testing by Columbia during the acceptance tests indicated severe limitations in the ability of the shadow band solar trackers to accurately track the sun during the range of sky conditions experienced in Columbus, Ohio. This situation was discussed with Honeywell, and Columbia was assured that control system modifications to correct this problem would be implemented in the Columbia solar trackers. With this assurance, Columbia accepted the solar energy system. The Columbia acceptance test plan for the Highlights Building solar energy system is contained in Appendix F.

VII. POST INSTALLATION SOLAR SYSTEM MODIFICATIONS

Several modifications of the Highlights Building Solar Energy System have been made since the system was installed. These modifications were undertaken to correct original design deficiencies and to improve system performance and reliability. The following identifies the major improvements made to the solar system.

A. Sensor Modifications

The Highlights Building solar energy system is monitored with a DOE furnished Site Data Acquisition System (SDAS). The sensors for the site data acquisition system were installed by Columbia as directed by I.B.M. Federal Systems Division. The two Ramapo MARK-V flow meters supplied by I.B.M. for the domestic hot water measurement were fabricated with a stainless steel strain gage connection flange and a brass line housing. The joint between the stainless steel flange and the brass body failed on both of these flow meters soon after installation. These two flowmeters were removed and two new Ramapo flowmeters installed. I.B.M. Federal Systems Division then identified that the intermittent flow pattern of the domestic hot water system could not be accurately established with SDAS instantaneous flow rate scans every 5.33 minutes.

At I.B.M. Federal Systems Division's request the two Ramapo flow meters used to measure domestic hot water flow were replaced by accumulating flow meters with magnetic pickups. These flow meters did not operate properly with the hot water supplied by the solar system and were often subject to seizing. This gave rise to periods when the flow meter was continuously indicating no flow.

The domestic hot water plumbing was changed a third time to accept Hersey American water meters. These water meters have improved the reliability and accuracy of the domestic hot water flow measurements. However, several repairs of these meters have also been required.

B. Solar Collector Drive Motor Modifications

The Highlights Building solar collector drive motors have an integral cone brake that does not allow the motor to coast when the motor is de-energized. The DEMAG cone brake motors selected by Honeywell had steel-on-steel brake surfaces. The motors delivered to the site were not weatherproofed, although they were specified for outdoor installation. Constant exposure to ambient moisture during the construction phase of the program caused all of the cone brake surfaces to rust together. When the solar collectors were authorized by the controls to rotate into the track position, the solar collector drive motors could not rotate due to the brake lining rusting and adhering to the cone.

The situation was further aggravated by the accumulation of rain water in the bottoms of several of the motor cases. The drive motors were temporarily modified by installing a rubber gasket in the motor end-bell to minimize direct rain penetration. However, ultimate solution of the problem required installation of weatherproofed end-bells and sealing of the electrical junction boxes on the motors to prevent moisture intrusion into the motor housings and electrical junction boxes.

C. Solar Collector Speed Reducers Repairs

Winsmith 5000:1 speed reducers were supplied by Honeywell with the solar collectors. Many of the speed reducers have developed gasket leaks between the speed reducer housing and the intermediate shaft adapter. The problem in every case has been corrected by replacing the gasket and properly tightening the bolts that hold the intermediate shaft adapter to the housing. This repair, which requires several man-hours of field labor to repair each gear reducer, appears to be necessary only because the bolts are not properly tightened at the factory. No re-occurrence of the problem has been noted for any repaired units.

One flexible coupling between the electric motor and the speed reducer slipped on the shaft. The coupling contacted the cone flange motor mount which prevented that solar collector row from rotating. All of the electric motors and couplings in the field were removed and the couplings were retrofitted with two set screws to prevent them from moving on the shaft.

D. Solar Collector Absorber Tube Housing Modifications

The glass cover on the absorber tube housing are held in place with aluminum strips fastened with small screws. At times when the concentrated solar flux line from the reflector panel is focused on these aluminum strips, the aluminum strip becomes hotter than the aluminum housing. The differential expansion between the aluminum strips and the aluminum housing is sufficient to shear the small screws. The screws that were sheared off in the hole were removed and all screws were replaced with slightly larger screws.

The aluminum hold down strips have been retrofitted with slotted holes to allow for the differential expansion.

E. Solar Collector Panel Modifications

The Hexcel reflector panels used in the Honeywell solar collector are equipped with extruded plastic edge caps to prevent water from entering the honeycomb panel. These end caps were attached to the reflectors with epoxy, and are sealed with silicon rubber caulk at the joint between the edges of the caps and the surfaces of the reflector panel.

During the first winter the solar system was installed, differential thermal expansion of the aluminum reflector panels and the plastic edge caps caused the silicon rubber caulk joint to break, and caused many of the caps to crack as shown in Figure 15.

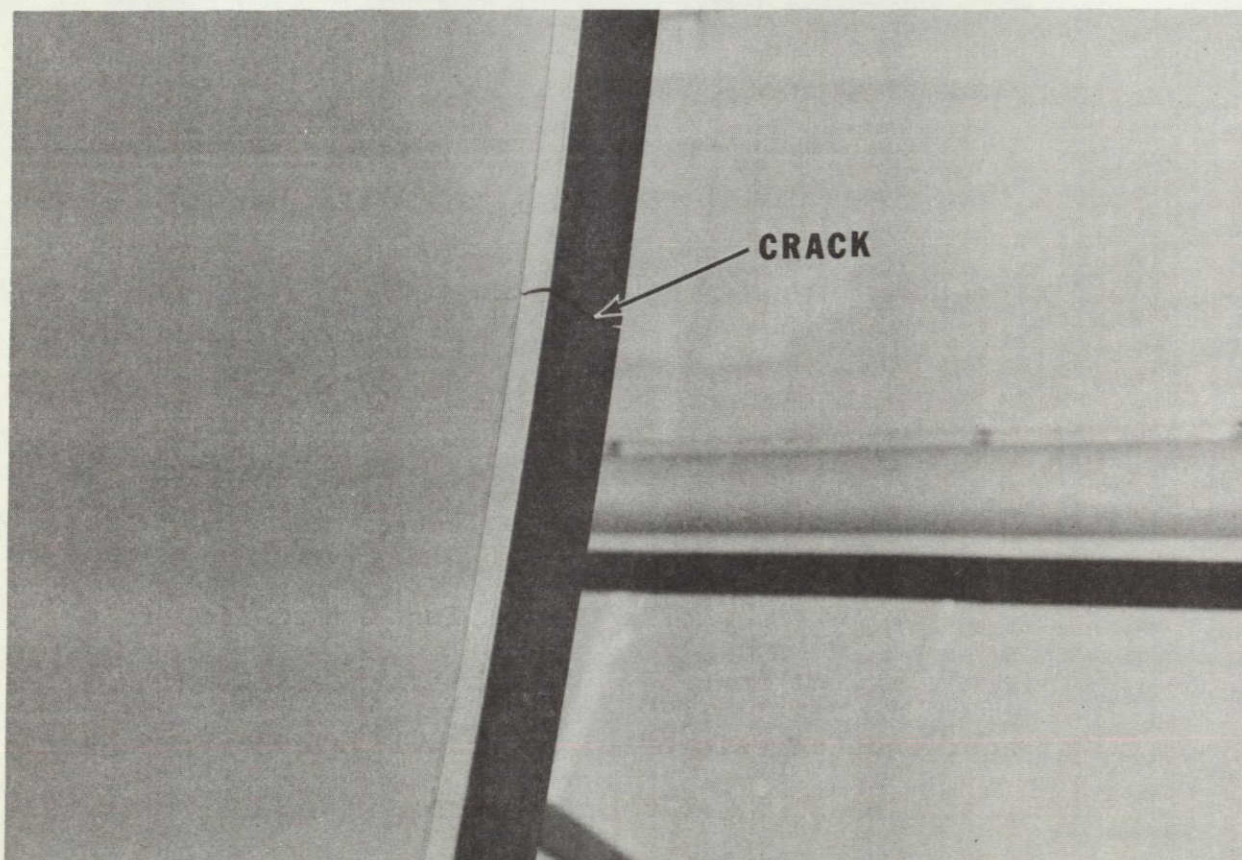


FIGURE 15

This permitted water to enter into the edges of the reflector panel and to penetrate beneath the edges of the reflective tape which forms the surface of the solar mirror. Representatives of Hexcel Corporation, the solar reflector panel manufacturer, visited the site in July of 1979. Hexcel attempted to identify a satisfactory method for field removal of the plastic edge caps, and replacement with extruded aluminum edge caps, without success. The plastic edge caps were left in place and cracks were sealed with silicon rubber caulk.

In October of 1979, 3M Corporation representatives visited the Highlights Building solar energy system site. All locations on the solar collector panels that had FEK-244 acrylic film delamination were repaired. The film was removed using a heat gun, solvent cleaned and new FEK-244 sections were applied. This repair procedure appears to give excellent results.

Honeywell installed stiffening ribs on the back side of the solar reflectors during fabrication of the solar collector panels. These stiffening ribs were permanently mounted with epoxy adhesive, but were positioned and held in place by aluminum angle and screw fasteners until the epoxy set. These aluminum angle sections and screws were left in place in the finished collectors as shown in Figure 10.

Water entered the back side of the solar reflectors through these screw fastener holes and this water penetrated the cell structure of the reflector panel. Exposure to a series of freeze-thaw cycles during the winter of 1978, caused the aluminum skin of the reflector panel on the concave side of the panel to separate from the cell

structure, forming a blister. In some cases, additional moisture penetrated the adjacent cells, which were exposed by separation of the aluminum skin, causing the blister to expand. Appendix G contains information on each collector panel identifying the number and size of the freeze blisters on the reflective surface. Columbia estimates that total reflective surface loss is approximately 1%. Figure 16 shows one of the largest blisters. Columbia, Honeywell and Hexcel have concluded that there is no practical way to field-repair this damage. Columbia carefully caulked and sealed all of the holes in the reflector panel and painted the adjacent surfaces of the stiffener and the parabola to retard further moisture penetration.

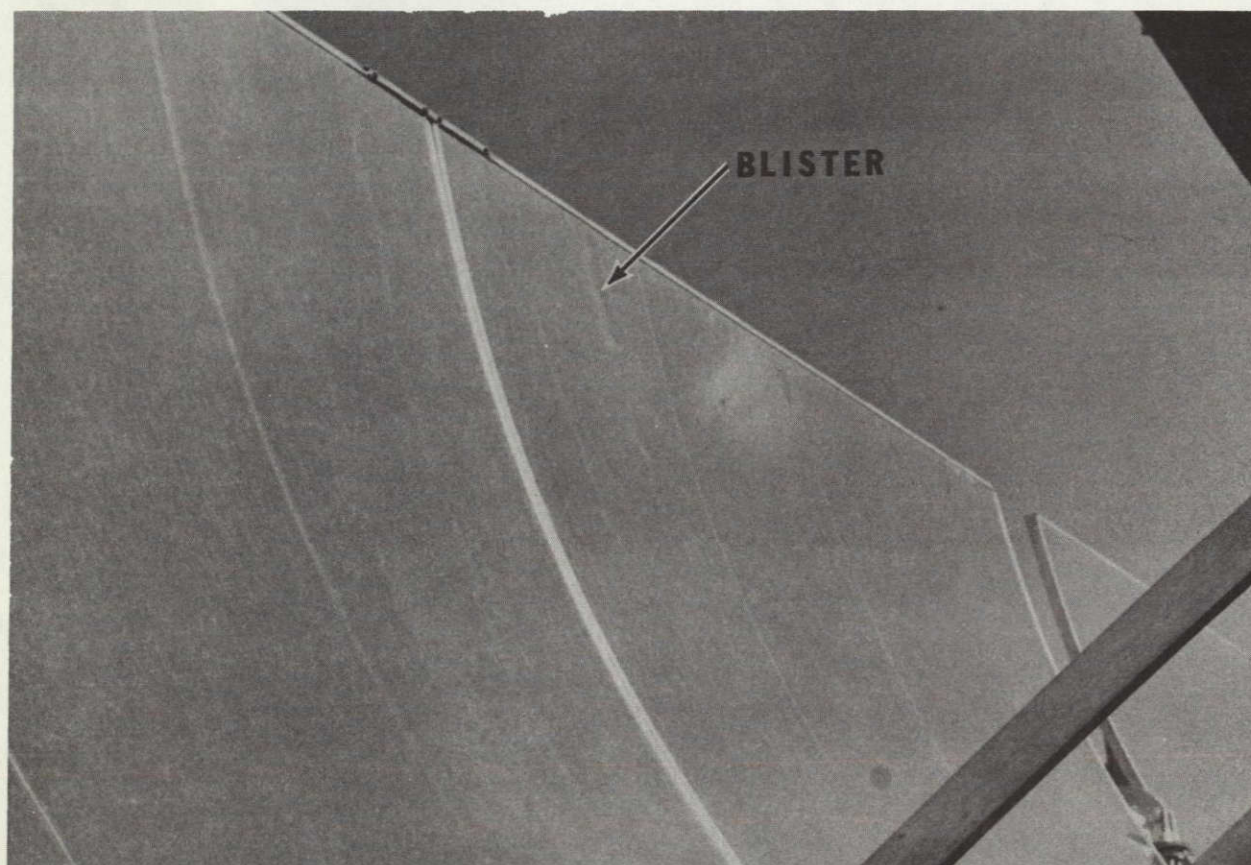


FIGURE 16

F. Addition of Solar Collector Panel Counterweights

Observation of the operation of the solar collector field through the winter of 1978-1979 indicated significant, but apparently inconsistent, misalignment of the concentrated solar flux on the absorber tubes. Further investigation revealed that a major portion of this misalignment was the result of torsional twisting of the reflector structure. The torsional moment which caused this twisting was the result of mounting the reflector panels and absorber tube from one side of the torque tube which is the main structural member of the solar collector. This unbalanced load on the torque tube introduced maximum torsional moment during the winter, particularly in the early morning or late evening hours, when the reflector panel was nearly vertical and the length of the moment arm was at its maximum. The unbalanced torsional loading introduced approximately 1-3/4 degrees of rotation, at the outboard ends of each collector row. Under these conditions, if the solar flux line was perfectly focused on the absorber tube at the center of each row, the center of the solar flux line was 1-1/2 inches below the center of the absorber tube at the ends of each row.

This problem was corrected by installation of a series of counterweights. The design of the counterweight system is presented in Appendix H. The system requires three counterweights on each collector half row. These counterweight assemblies were mounted on the torque tube opposite the solar collector panel and absorber tube assembly as shown in Figure 17. The installation of this counterweight system has virtually eliminated torsional misalignment of the solar collector field.

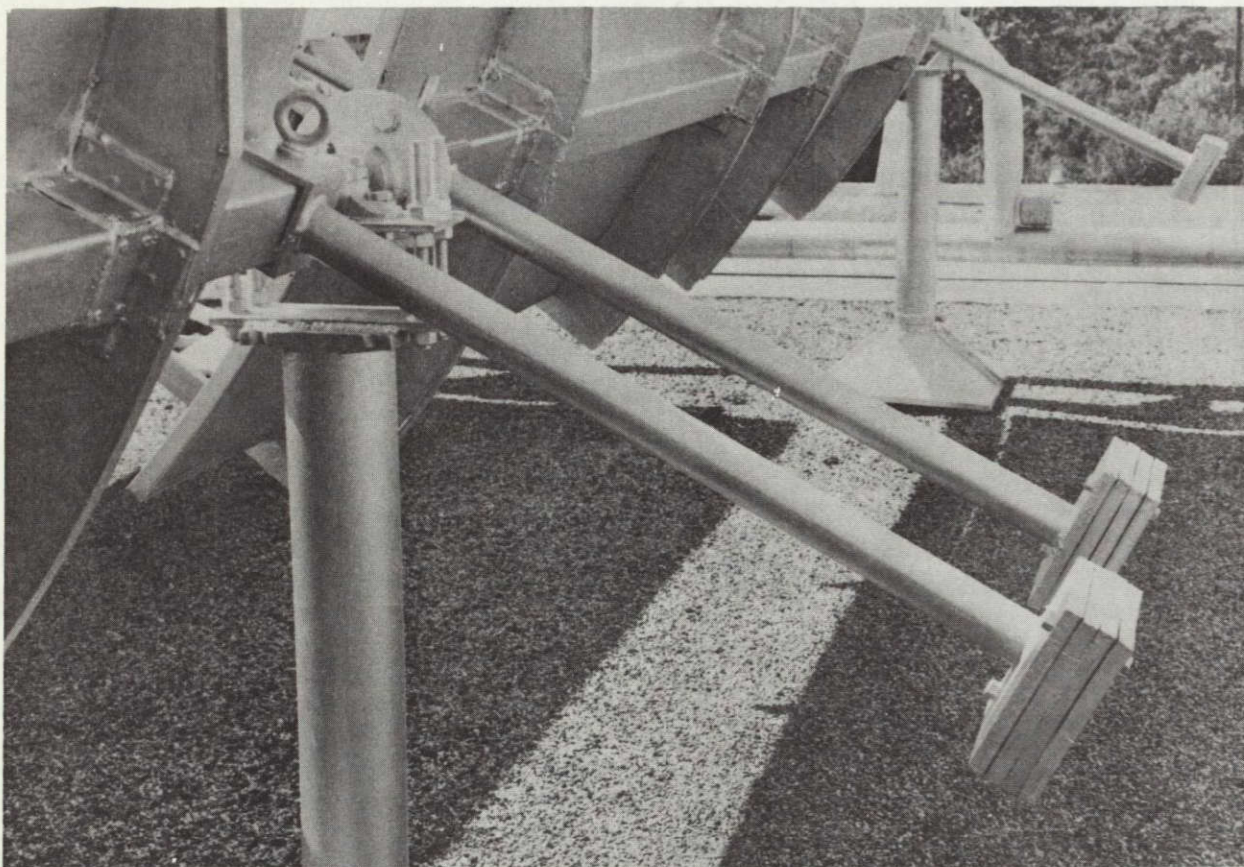


FIGURE 17

G. Storage Tank Insulation Modification

The 5,000 gallon solar energy storage tank at the Highlights facility is insulated with four inches of 8 pound density mineral wool insulation covered with a hard Portland cement finish. The legs of the solar energy storage tank, the access manhole, and two large tank inlet and outlet valves were not insulated during the construction of the solar energy system. Early testing of the system, and data from the DOE SDAS, indicated high storage losses. Columbia contracted with Earl Bright & Company to install insulation on the legs of the storage tank, the access manhole and the inlet and outlet

line manual valves immediately adjacent to the storage tank. This insulation consisted of one inch of Armaflex foam insulation on the legs of the storage tank, a four-inch thick removable fiberglass cover on the access manhole and three inches of fiberglass insulation on the large inlet and outlet valve bodies. This reinsulation of the storage tank resulted in a reduction of approximately 44% in stored energy losses.

Storage tank losses, solar collector loop and solar storage loop warm-up/cool-down losses, and a portion of the energy delivered to the domestic hot water currently range from 180,000 BTU/day during the winter (when the average storage tank temperature is lower) to 400,000 BTU/day during the summer (when the average storage tank temperature is higher). The instrumentation at the site has had numerous periods when the energy delivered from the storage tank to the domestic hot water system has not been measureable (see Section A above). Since energy delivered from the tank to the DHW is uncertain, the derived tank losses are uncertain. Other problems with the I.B.M. SDAS, which have been discussed in great detail in the technical literature, also preclude absolute faith in the tank loss rates quoted above.

H. Sun Tracking Controls Replacement

The sun tracking units for the Highlights Building concentrating solar collectors were Delavan Sun-Loc 1 units modified by Honeywell. The Sun-Loc 1 system is a shadow bar type of sun tracker which controls a motor drive unit that points the collector at the sun. This tracker derives its control signal from two phototransistors which are positioned so that their signals are equal when the device

is pointed at the sun. The electronics process this condition as a null signal. When the sun moves, it illuminates one phototransistor and the shadow of the "shadow bar" falls on the other phototransistor disrupting the null condition and causing a signal that is used to control the collector motor drive. The collector is moved until the signal is again nulled. This concept can be mechanized with low cost components. However, operation of this type of unit in the field uncovered a number of operational problems.

If the sun tracker was adjusted to track the sun well on clear bright days, the collectors were sluggish and did not track satisfactorily on less bright days. If the sensitivity of the sun tracker was increased, the collectors tracked satisfactorily on less bright days, but the tracker became too sensitive on clear bright days and the collector oscillated continuously, driving the motor alternately forward and reverse in short bursts. This collector oscillatory motion, or "hunting", caused the collector drive motor to overheat and the collector row was disenabled by the motor thermal overload.

Several techniques were investigated for economically controlling solar tracking collectors. This effort included evaluation of improvements to the existing shadow-band tracking controller, an advanced shadow bar tracking system, an open loop tracking system and a flux-line tracking system. These evaluations considered the requirements of solar thermal installations with single-axis tracking systems. Based on this evaluation, tracking concepts in which the tracking error budget contained the fewest number of variables: that

is, tracking the flux line itself and mechanically coupling the tracking sensors to the absorber tube, appeared to be the most promising.

A Flux Line Sun Tracker (FLST) Control System developed by Honeywell, Inc. was evaluated at the Highlights Building solar site. The FLST consists of two primary parts, the sensor head and the electronic controller. The sensor head is mounted to the absorber tube housing and contains sensors positioned on each side of the absorber tube. In operation the flux line reflected from the solar reflector panels is focused between the sensors and on the absorber tube. The electronic controller acts to keep the flux line between the sensors. The philosophy of the control system is hence to position the flux line on the absorber tube rather than to point the reflector panel towards the sun. One of the advantages of this approach, compared with the shadow-band sensor, is the elimination of the difficult roll-axis alignment and pitch-axis alignment between the shadow-band sensor and the reflector panel.

Columbia tested both an early hand-wired prototype and a later printed circuit board model of the Honeywell Flux Line Sun Tracker at the Highlights solar site in Columbus, Ohio. In our tests the Flux Line Sun Tracker exhibited high accuracy and reliability in placing the flux line on the absorber tube. The tracking accuracy of this tracker, over the wide range of solar radiation levels that produce useful solar energy collection, is significantly better than any of the three shadow-band trackers that we previously investigated. After proper mounting of the sensor head, the electronic positioning

commands appear to be accurate to within about 0.2 degree depending on solar radiation intensity. Repeatability of electronic positioning appears to be accurate within about 0.1 degree. The tracking accuracy of the Flux Line Sun Tracker is sufficiently high to make collector tracking accuracy primarily a function of the dynamics of the drive motor, the drive motor cone brake, the drive motor/speed reducer coupling, etc. rather than the tracker/controller.

The electronics are designed to utilize microprocessor based components to achieve the required logic functions. The primary function of the circuit is to balance the sensor outputs by initiating movement of the collector (via the drive motor). Secondary functions of the circuit include search and acquire logic, collector position logic, and manual control capability. With the sensors operating in the edge of the concentrated flux beam, the voltage balancing circuitry can be properly thresholded to ignore any changes in skylight, diffuse light, or extraneous scattered light while tracking the concentrated beam from the sun. In Columbia's testing of the tracker, it was found that the microprocessor logic prevented the collector oscillatory, or "hunting", motion that occurred with the shadow-band controller circuitry.

In February of 1980, the shadow-band sun tracking sensors and control electronics were replaced with the Honeywell FLST control systems on all eleven rows of single-axis tracking solar collectors at the Highlights site.

I. Solar Collector Wake-up Sensor Replacement

In addition to sun tracking control problems, the Highlights Building solar energy system was fitted with a sub-optimal wake-up controller. An Eppley Model 8-48 pyranometer that senses total solar radiation was mounted on a fixed surface tilted at 40 degrees. The pyranometer provided an analog signal that was electronically processed to generate a contact closure when the solar radiation was above a threshold level. This threshold level could be manually adjusted and the electronics were designed with a relay contact differential so that the tracking system was enabled at a slightly higher solar radiation level than that at which it was disabled. This prevented short cycling of the solar collector drive motors.

A 40:1 concentration ratio solar collector collects primarily direct or beam solar radiation. An optimum wake-up controller for a concentrating collector should be based on direct normal insolation rather than total insolation. If total insolation sensors are used to generate a wake-up command for a concentrating solar collector the effects of sun angle and the ratio of diffuse to beam radiation must be continuously calculated and used to correct the raw total radiation sensor analog output.

Because of the inherent limitations of an automatic wake-up controller based on total solar radiation, Columbia investigated other approaches to wake-up control. Wake-up controls based on a direct normal insolation measurement, rather than a total insolation level were considered. Direct normal reading pyrheliometers which are available can provide this function. However, Columbia's two pyrheliometers at the Highlights Building site, while very accurate,

require continuous attention and adjustment. The proposed approach to upgrading the wake-up sensor was to closely approximate the desired direct normal insolation measurement with a device that has no moving parts and does not require tracking mechanisms.

Honeywell developed and tested a concept that utilizes eight silicon photo sensors mounted in a semi-circular array, each sensor having a field of view of approximately 30° in azimuth and 50° in elevation. The $30^\circ \times 50^\circ$ field of view is a compromise between the total hemisphere field of view for a pyranometer and the desired 3° conical field of view of a tracking pyrliometer. The combination of eight sensors provides complete coverage of all sun angles throughout the year; thus, no periodic adjustments are required. The outputs of all eight sensors are continuously monitored and the maximum signal level of the eight sensors is compared to an adjustable reference voltage. If the maximum signal value exceeds a preset level an output wake-up command is provided to the solar collector field.

Columbia replaced the pyranometer wake-up sensor at the Highlights Building solar energy system with a Honeywell wake-up sensor and controller in February, 1980, in order to assure the solar collector system will be activated at all times when collectible direct normal solar radiation is available for the solar collectors.

VIII. SOLAR SYSTEM PERFORMANCE

A summary of the operation of the Highlights Building solar energy system for calendar year 1979 and the first seven months of 1980 is presented in Table 3 and Table 4. Table 3 summarizes the solar system performance based on total solar radiation available on the solar collector surface. Since high concentration ratio solar collectors nominally only collect beam solar radiation, the efficiency of these collectors is often reported as a percentage of beam solar radiation. Table 4 reports solar collector performance based on beam solar radiation available.

As shown in Table 3, data for the first seven months of 1980, compared to the first seven months of 1979, indicates the solar collector efficiency has been improved from 11.9 to 20.0 percent of total seasonal solar radiation. Concomitantly, as shown in Table 4, the solar collector efficiency has been improved from 20.0 to 33.8 percent of seasonal beam solar radiation. This increase in solar radiation collection is primarily due to:

- Addition of solar collector panel counterweights in April, 1979. (Discussed in Section VII, Paragraph F).
- Change from attended five-day per week solar system operation before May, 1979 to unattended seven day per week solar system operation after May, 1979.
- Sun tracking controls replacement in February, 1980. (Discussed in Section VII, Paragraph H).
- Solar collector wakeup sensor replacement in February, 1980. (Discussed in Section VII, Paragraph I).
- Solar collector absorber tube realignment by Honeywell and Columbia technicians in May, 1980.

HIGHLIGHTS BUILDING SOLAR ENERGY SYSTEM
SOLAR ENERGY COLLECTED

Month	1979 Solar Radiation Available* (Million BTU)	1979 Solar Radiation Collected (Million BTU)	1979 Solar Collector Efficiency (Percent)	1980 Solar Radiation Available * (Million BTU)	1980 Solar Radiation Collected (Million BTU)	1980 Solar Collector Efficiency (Percent)
Jan	60.9	5.7	9.4	59.6	5.4	9.1
Feb	83.1	8.7	10.5	82.8	13.3	16.0
March	97.4	8.9	9.2	95.0	15.2	16.0
April	100.3	9.7	9.6	105.0	20.5	19.6
May	139.6	28.0	20.0	129.5	25.7	19.9
June	141.4	18.7	13.2	143.4	40.8	28.4
July	142.7	11.2	7.8	133.7	28.9	21.7
August	146.5	19.3	13.2			
September	127.7	23.6	18.5			
October	79.1	9.3	11.7			
November	78.5	13.9	17.7			
December	68.5	10.5	15.4			
Total Jan-July	765.4	90.9	11.9	749.0	149.8	20.0
Total for Year	1265.8	167.5	13.2			

* Total Solar Radiation on 2978 square feet of surface tilted at 40 degrees in Columbus, Ohio

Table 3

HIGHLIGHTS BUILDING SOLAR ENERGY SYSTEM
SOLAR ENERGY COLLECTED

<u>Month</u>	<u>1979 Solar Radiation Available* (Million BTU)</u>	<u>1979 Solar Radiation Collected (Million BTU)</u>	<u>1979 Solar Collector Efficiency (Percent)</u>	<u>1980 Solar Radiation Available * (Million BTU)</u>	<u>1980 Solar Radiation Collected (Million BTU)</u>	<u>1980 Solar Collector Efficiency (Percent)</u>
Jan	35.7	5.7	16.0	32.6	5.4	16.6
Feb	49.3	8.7	17.6	50.5	13.3	26.3
March	57.4	8.9	15.5	57.4	15.2	26.5
April	53.3	9.7	18.2	62.2	20.5	33.0
May	92.0	28.0	30.4	71.2	25.7	36.1
June	79.2	18.7	23.6	93.3	40.8	43.7
July	87.8	11.2	12.8	76.0	28.9	38.0
August	90.2	19.3	22.2			
September	85.0	23.6	27.8			
October	43.3	9.3	21.5			
November	55.9	13.9	24.9			
December	51.2	10.5	20.5			
Total Jan-July	454.7	90.0	20.0	443.2	149.8	33.8
Total for Year	780.3	167.5	21.5			

Direct Solar Radiation on 2978 square feet of surface tilted at 40 degrees in Columbus, Ohio

TABLE 4

The Highlights Building solar energy system collected 167.5 million BTU's of thermal energy in 1979. It is projected that the system should collect 264 million BTU's of thermal energy in 1980.

Columbia's technical proposal to U.S. DOE in November of 1976 projected that the proposed solar energy system would provide 33% of the energy required for space heating, space cooling and domestic hot water in the Highlights Building. This projection was based on a proposed system with 12 rows (3324 ft²) of solar collectors and an annual building energy consumption of 2656 MCF/year.

The Highlights Building annual thermal energy requirements have changed and are currently 71 percent higher than in November of 1976 when Columbia's technical proposal was prepared. Solar collector array seasonal efficiency is 42 percent lower than projected from Honeywell solar collector efficiency data. The actual beam solar radiation available in Columbus, Ohio is 20 percent less than estimated from information available in 1976. The actual solar collector array installed is 10 percent smaller than originally anticipated. The combined effect of the above changes has changed the anticipated annual solar fraction to 7 percent of the energy required for space heating, space cooling and domestic hot water. The above changes are discussed in detail in Appendix I.

APPENDIX A. .

HIGHLIGHTS BUILDING PHOTOGRAPHS



FIGURE 20

(North)

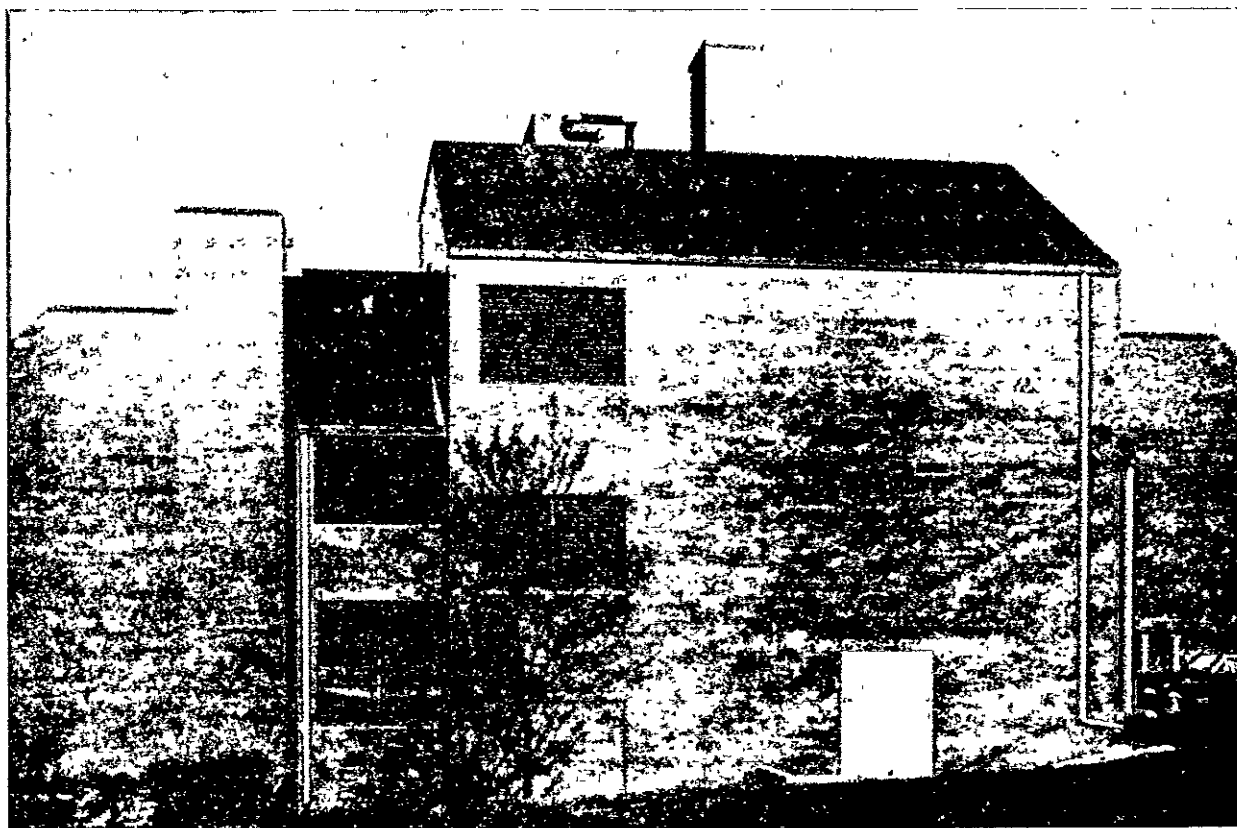


FIGURE 21

(East)

Reproduced from
best available copy.

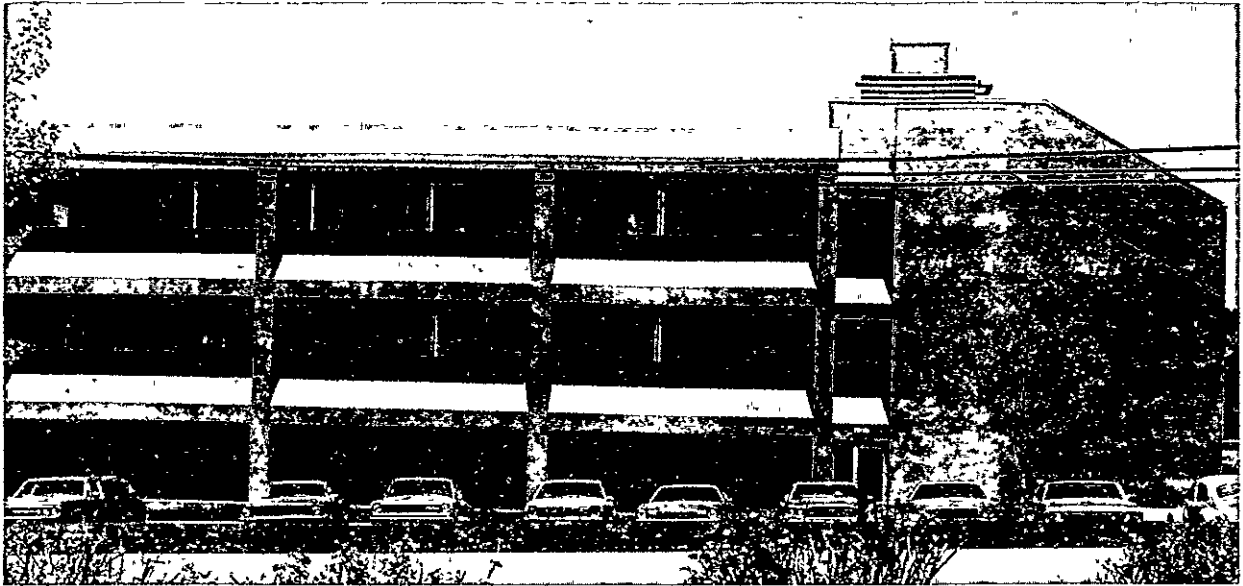


FIGURE 18

(South)

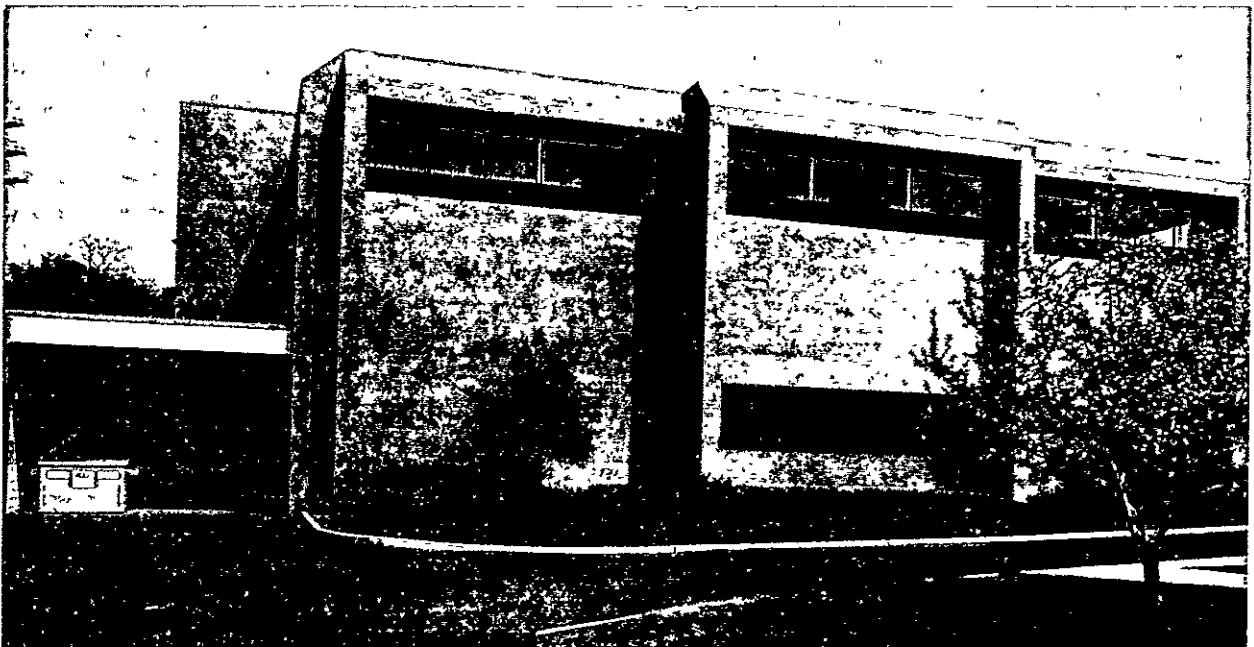


FIGURE 19

(West)

ORIGINAL PAGE IS
OF POOR QUALITY

APPENDIX B.

HIGHLIGHTS BUILDING FLOORPLANS

64-A

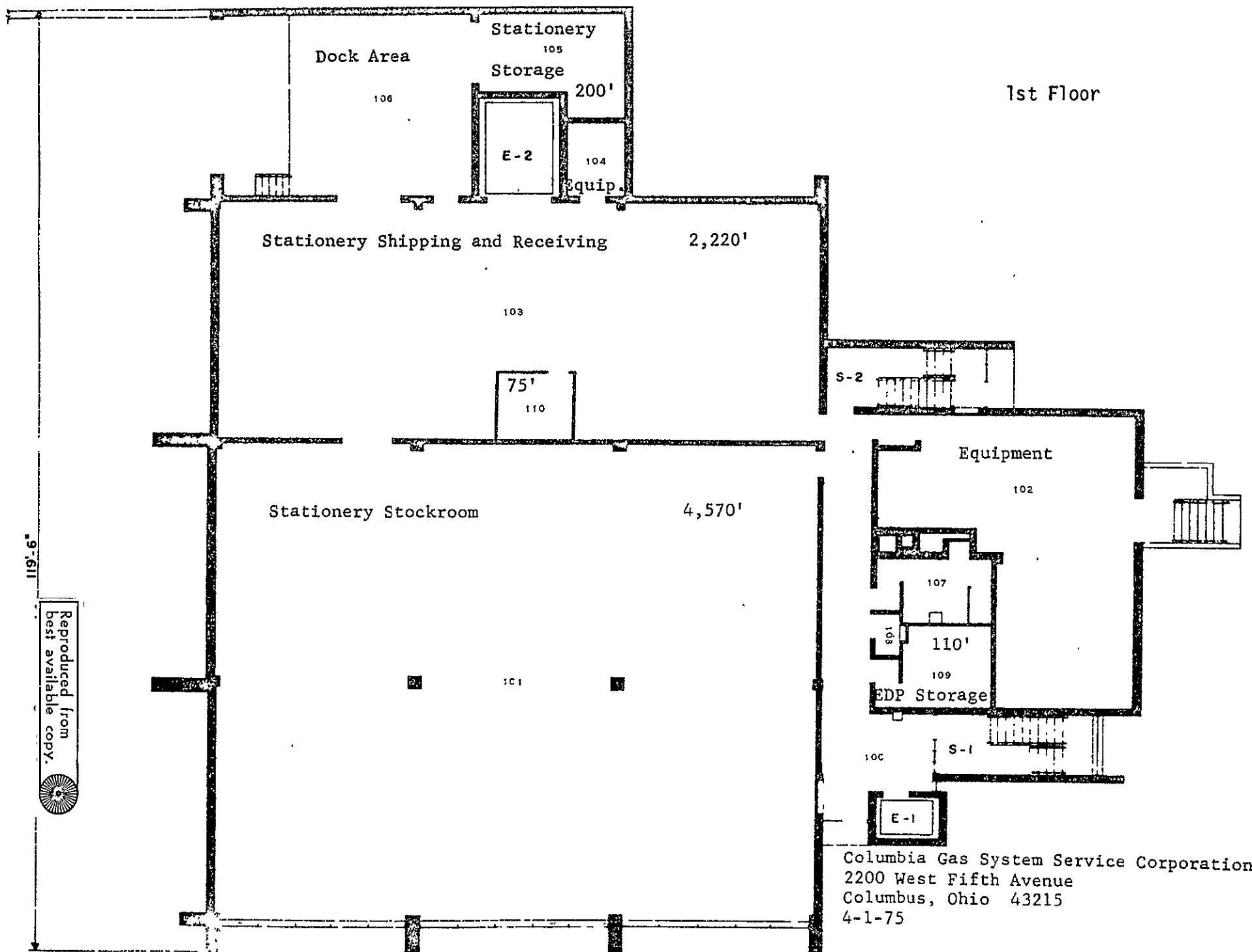
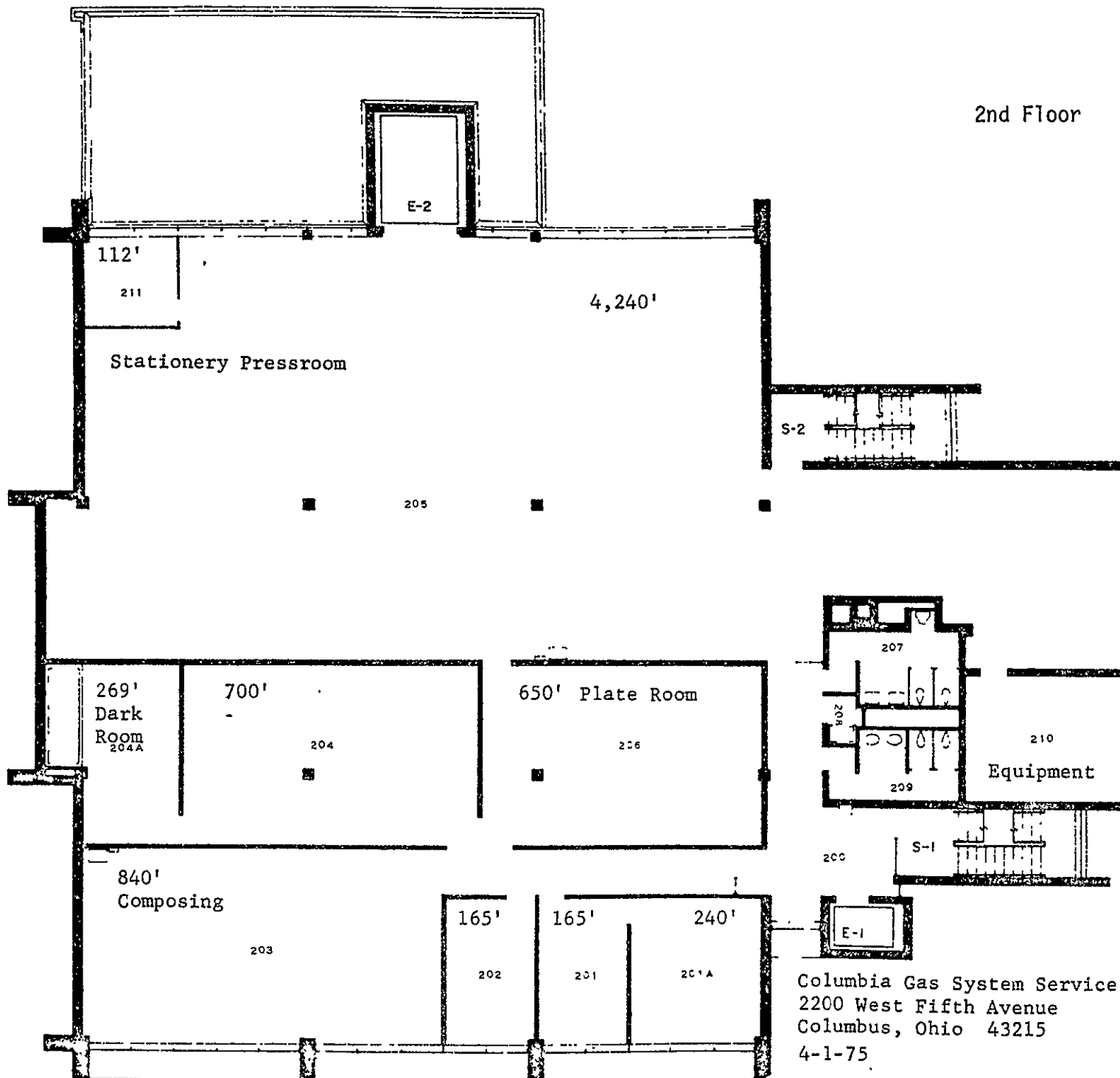
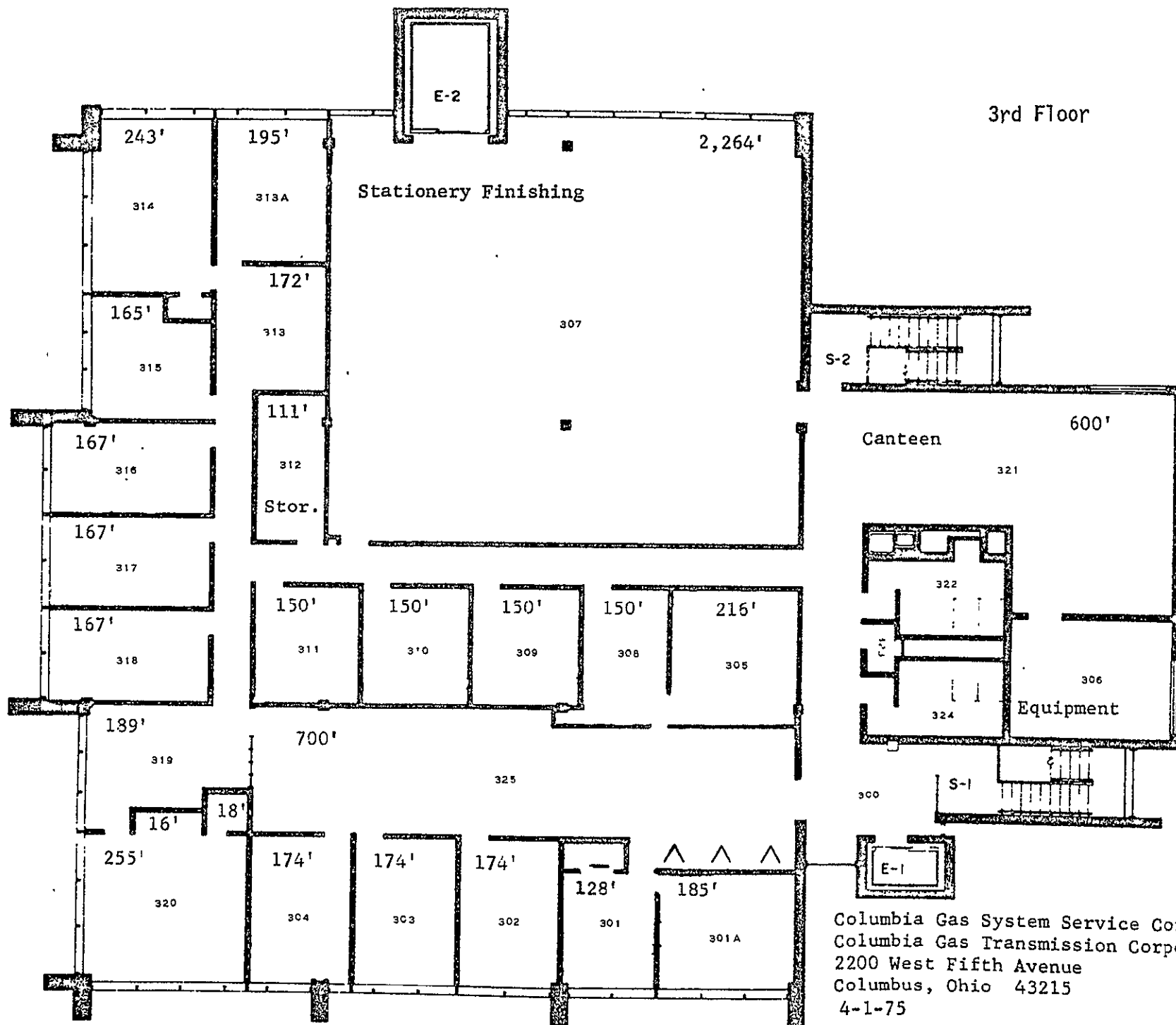


FIGURE 22



Columbia Gas System Service Corporation
 2200 West Fifth Avenue
 Columbus, Ohio 43215
 4-1-75

FIGURE 23



Columbia Gas System Service Corporation
 Columbia Gas Transmission Corporation
 2200 West Fifth Avenue
 Columbus, Ohio 43215
 4-1-75

FIGURE 24

APPENDIX C.

SOLAR ENERGY SYSTEM CONTROL DRAWINGS

APPENDIX D.

SOLAR SYSTEM COMPONENT SPECIFICATIONS

APPENDIX D.

SOLAR SYSTEM COMPONENT SPECIFICATIONS

Many standard manufacturers' products were selected and purchased for the Highlights Building solar energy system. The following is a brief summary of the technical specifications of the major solar system components. The manufacturer's company address and phone number is included for reference and further information on these components.

A. Solar Collector Drive Motor

Each solar collector row is driven by a centrally located brake motor which is flange-mounted on a speed reducer. The brake-motor combines a cone brake and electric motor into an integral unit. When the motor is energized, an axial component of the magnetic field overcomes the force of the brake spring and pulls the rotor into the stator and away from the cone brake. This slight shift of the rotor creates a conical air gap between the brake stator and brake rotor and allows the motor to run. When the motor is de-energized the brake spring pushes the brake rotor surface into the brake stator, stopping the motor.

Each solar collector row has a continuous duty 0.59 HP squirrel cage brake motor with a 100 percent duty factor. The full load torque and full load speed are 1.9 ft-lb and 1645 rpm, respectively. The brake motor operates on 208V, 60 Hz, 3 phase power.

Manufacturer: DEMAG Corporation
Industrial Drives Division
29201 Aurora Road
Cleveland, Ohio 44139

Motor Type: KBA 71A

Number of Poles: 4

B. Solar Collector Speed Reducer

Each solar collector row is driven by a centrally located drive unit. The drive unit includes a drive motor, a speed reducer and a local control box. The speed reducer is a triple reduction worm gear reducer with a 5000:1 reduction ratio. The speed reducer has two output shafts.

Manufacturer: Winsmith Division of UMC Industries, Inc.
Springfield, N. Y. 14141
Telephone: 716/592-9311

Product Number: 8CBTM

Model Number: C-0821M-61B-00

C. Solar Heat Exchanger

Heat is exchanged between the solar collector fluid loop and the storage loop in a shell and straight tube heat exchanger. The heat exchanger is designed for a tube side (solar collector loop) flow rate of 75 gpm operating with 44% by volume Dowtherm SR-1 and 56% by volume water. The shell side (solar storage loop) design flow rate is 95 gpm operating with rust inhibited water. The tube side (hot loop) design inlet and outlet temperatures are 230.0°F and 212.3°F, respectively. Shell side design inlet and outlet temperatures are 200.0°F and 213.1°F, respectively. The heat exchanger effectiveness at these conditions is 60 percent, and the design heat transfer rate is 600,000 BTU/hour. The total heat exchange surface area is 178 square feet.

Manufacturer: Bell and Gossett
Fluid Handling Division
8200 North Austin Avenue
Morton Grove, Illinois 60053

Model Number: OF 1011-14

D. Solar Collector Loop Pump

The solar collector loop pump is a line-mounted, vertical, close-coupled, centrifugal pump. The design flow rate for the pump is 75 gpm operating with 44% by volume Dowtherm SR-1 and 56% by volume water with a pump head of 50 feet. The electric motor that drives the pump is a 2-HP, 1750 rpm, 60 Hz, 3-phase, 208 volt motor.

Pump Manufacturer: Thrush Products, Inc.
P. O. Box 228
Peru, Indiana 46970
Telephone: 317/472-3351

Pump Model Number: 2-TV-2-L

Pump Serial Number: 6722-B

Motor Manufacturer: Marathon Electric Manufacturing Corp.
P. O. Box 1407
Wausau, Wisconsin 54401
Telephone: 715/675-3311

Motor Model Number: FL 145TTDR8664AAW F1

Motor Frame Number: 145TCV

Motor Type: TDR BCVZ

E. Solar Collector Loop Expansion Tank

Fluid expansion in the solar collector loop is accommodated by a 120 gallon, 125 psig, ASME compression tank mounted inside the building in a penthouse at roof level. The tank is welded carbon steel and is fitted with a sight level gauge and airtrol fittings.

Manufacturer: Bell and Gossett
Fluid Handling Division
8200 N. Austin Avenue
Morton Grove, Illinois 60053

Product Number: 477721

Model Number: 120

F. Solar Thermal Energy Storage Tank

Solar energy is stored as sensible heat in a 5000 gallon, A.S.M.E. unfired pressure vessel. The tank has a design working pressure of 125 psi and is A.S.M.E. inspected and stamped. The tank is fitted with a 24 inch diameter inspection cover, a 150 psi ANSI flange to mount the domestic hot water heat exchanger (see paragraph I below), two 4 inch flanges for inlet and outlet water connections and various other fittings for the pressure relief valve, the drain valve and temperature sensors.

Manufacturer: Adamson Co., Inc.
13200 Ramblewood Dr.
Chester, Virginia 23831
Telephone: 804/748-6453

Product Line: Old Dominion Iron

Serial No. 114-R

G. Thermal Energy Storage Loop Expansion Tank

The solar thermal energy storage loop expansion is accommodated by a 529 gallon welded steel tank. The tank has a design working pressure of 125 psi and is A.S.M.E. inspected and stamped. The tank is fitted with a sight level glass and airtrol fittings.

Manufacturer: Adamson Co., Inc.
13200 Ramblewood Dr.
Chester, Virginia 23831
Telephone: 804/748-6453

National Board Number: 30748

Serial Number: 610-R

H. Solar Storage Loop Pump

The solar storage loop pump is a line-mounted, vertical, close-coupled, centrifugal pump. The design flow rate of the pump is 95 gpm operating on water with a pump head of 45 feet. The electric motor that drives the pump is a 2-HP, 1750 rpm, 60 Hz, 3-phase, 208 volt motor.

Pump Manufacturer: Thrush Products, Inc.
P. O. Box 228
Peru, Indiana 46970
Telephone: 317/472-3351

Pump Model Number: 2-TV-2-L

Pump Serial Number: 6722-A

Motor Manufacturer: Marathon Electric Manufacturing Co.
P. O. Box 1407
Wausau, Wisconsin 54401
Telephone: 715/675-3311

Motor Model Number: FL 145TTDR8664AAW F1

Frame Number: 145TCV

Type: TDR BCVZ

I. Domestic Hot Water Heat Exchanger

All city water flowing to the domestic hot water heater is preheated by solar energy in a heat exchanger immersed in the solar thermal energy storage tank. This domestic hot water heat exchanger is flange-mounted in the side of the solar energy storage tank as shown on Figure ME-2, page 82. The heat exchanger has 3/4 inch O.D. copper U-tubes with total surface area of 36.2 square

feet. The heater was specified to be supplied with brass heads. The heat exchanger is designed to heat 6.9 gpm of water from 40°F to 140°F when the solar energy storage tank temperature is 180°F. At these conditions the heat transfer rate is 345,000 BTU/hour.

Manufacturer: Bell and Gossett
Fluid Handling Division
8200 North Austin Avenue
Morton Grove, Illinois 60053

Model Number: TCW-696

J. Domestic Hot Water Temperature Control Valve

The domestic hot water system is fitted with a water mixing valve that automatically blends cold water with hot water delivered from the domestic hot water storage tank as required to limit the hot water delivery temperature. The mixing valve has an adjustable setpoint which can be set to limit the domestic hot water delivered to the building (i.e. limit the blended outlet water temperature from the mixing valve). This valve is required to temper the building hot water supply when the temperature of the solar preheated water in the domestic hot water heater exceeds the desired hot water delivery temperature.

Manufacturer: MCC powers
A Unit of Mark Controls Corporation
3400 Oakton St.
Skokie, Illinois 60076
Telephone: 312/673-6700

Product Number: 434-1065

Model Number: 2P10

K. Electric Generator

The Highlights Building solar energy system includes an emergency generator to drive the collectors to the stowed position in the event of a power failure. The electrical characteristics for the generator include 120/208 Voltage, 104 Amps, 60 Hz, 3 phase, 4 wire, 30.0 kW, 37.5 kVA at 0.8 PF. The generator has a Continuous Standby Rating. The engine operates on natural gas at 1800 rpm with speed regulation of 5 percent. The engine is a 6 cylinder, 4 cycle, overhead valve design.

Generator Manufacturer: Onan Corporation
1400 73rd Avenue, N.E.
Minneapolis, MN. 55432

Model Number: 30.0 EK-15R/1699K

Serial Number: A780293725

Engine Manufacturer: Ford Motor Company

L. Automatic Transfer Switch

An automatic transfer switch automatically starts the standby generating set on interruption of normal power and transfers the load when the set reaches proper speed and voltage. The transfer switch has the capacity for switching a continuous rating of 150 amps, and has two operating coils, electrically interlocked to provide positive, electrically guided action from "normal" to "standby" position. A mechanical interlock safety prevents both sources from supplying the load simultaneously.

Manufacturer: Onan Corporation

Model Number: #OTUDD150-4/12024

Serial Number: A780293906

APPENDIX E.

SOLAR ENERGY SYSTEM AS-BUILT DRAWINGS

76-A

HIGHLIGHTS BUILDING SOLAR ENERGY PROJECT

FOR

THE COLUMBIA GAS SERVICE CORPORATION

DIST. 77 - 98

COLUMBUS, OHIO

CONSULTING
ENGINEERS :

H.A. WILLIAMS & ASSOCIATES, INC.
COLUMBUS, OHIO

ARCHITECT :

KELLAM & SMITH,
ARCHITECTS / PLANNERS INC.
COLUMBUS, OHIO

AS-BUILTS
10-3-78

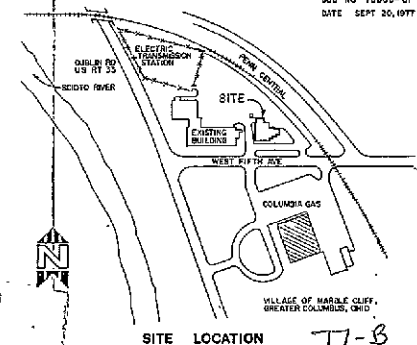
DRAWING INDEX :

- G-1 SITE PLAN & FLOOR PLANS
- G-2 WALL SECTIONS
- G-3 ROOF PLAN & DETAILS
- ME-1 MECHANICAL & ELECTRICAL
FLOOR PLANS
- ME-2 SYSTEM DIAGRAMS & DETAILS
- ME-3 ELECTRICAL ROOF PLAN
& DETAILS

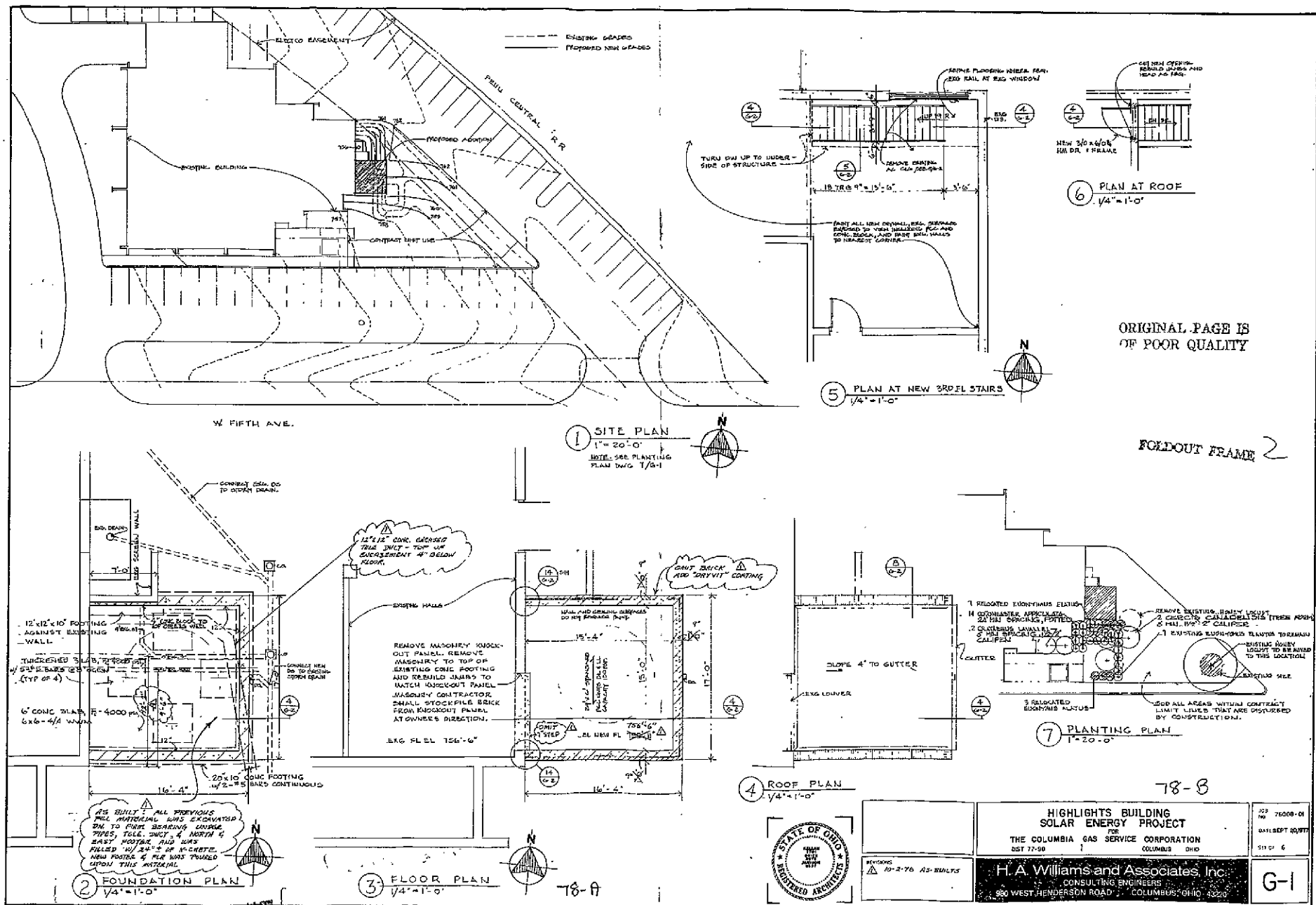
VOIDOUT FRAME

77-A

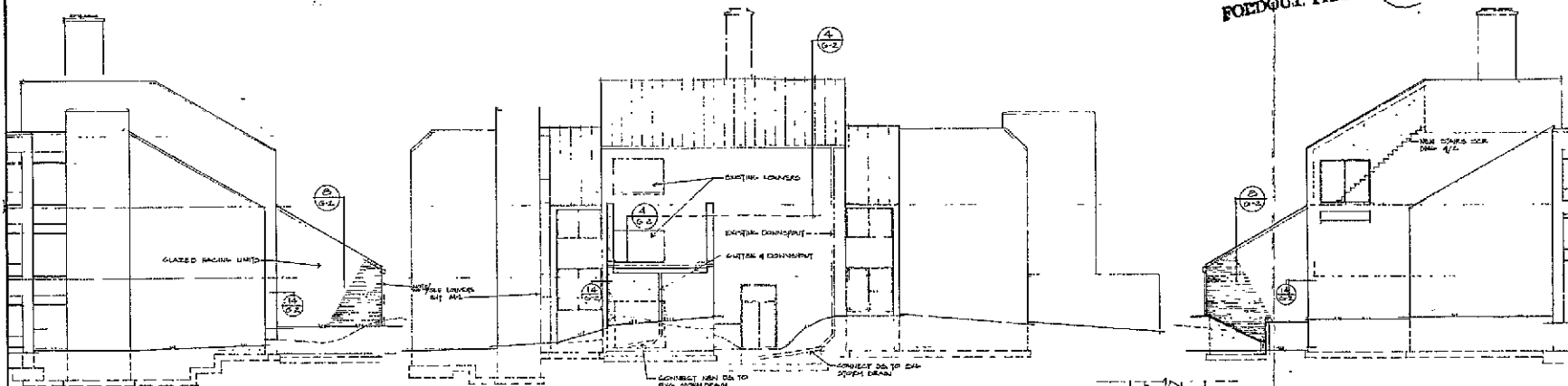
VOIDOUT FRAME



JOB NO. 75009-01
DATE SEPT 20, 1977



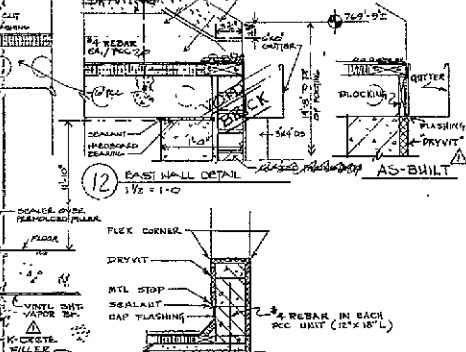
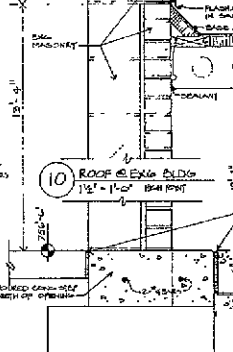
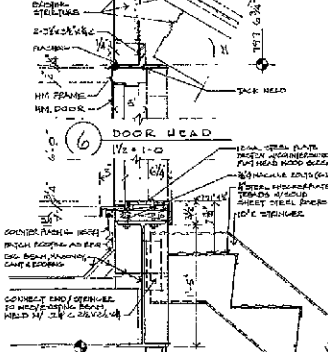
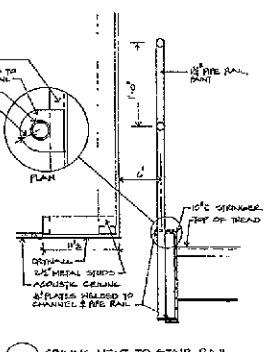
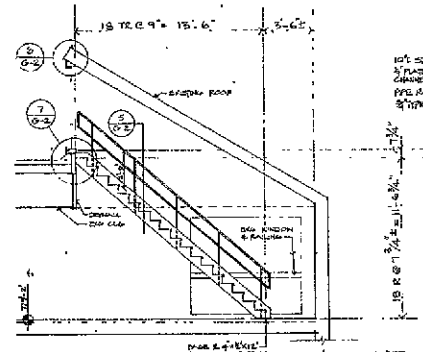
FOLOUT FRAME



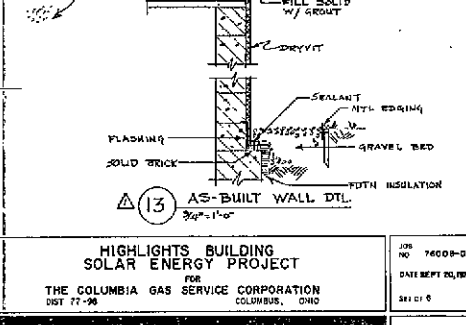
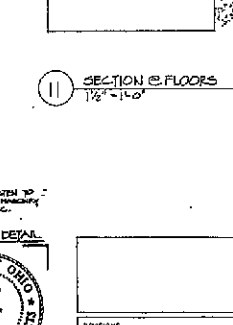
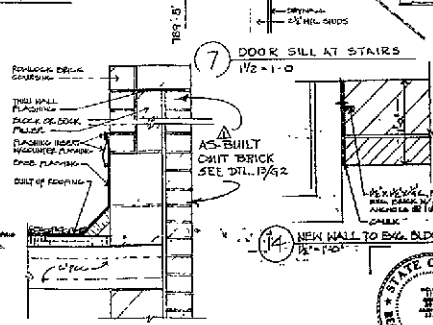
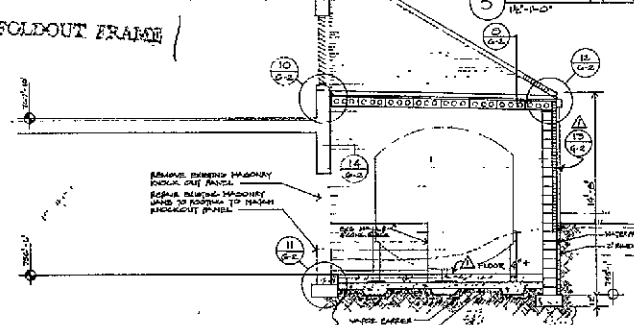
1 SOUTH ELEVATION
1/8" = 1'-0"

2 EAST ELEVATION
1/8" = 1'-0"

3 NORTH ELEVATION
1/8" = 1'-0"



FOLOUT FRAME



4 BUILDING SECTION
1/4" = 1'-0"

5 FLASHING DETAIL SIDE WALL
1/8" = 1'-0"

11 SECTION @ FLOORS
1/8" = 1'-0"

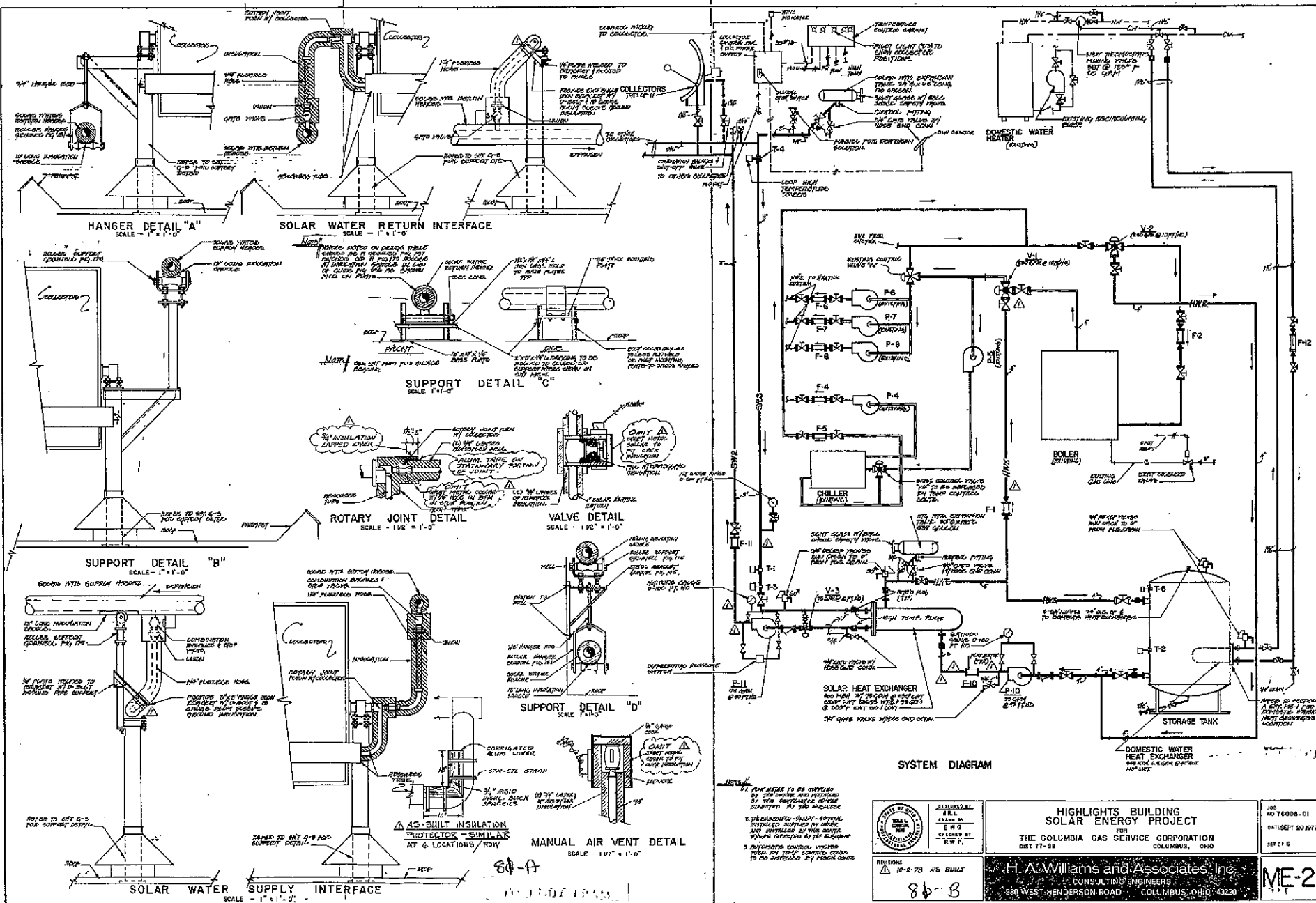
12 EAST WALL DETAIL
1/8" = 1'-0"

13 AS-BUILT WALL DTL
3/8" = 1'-0"

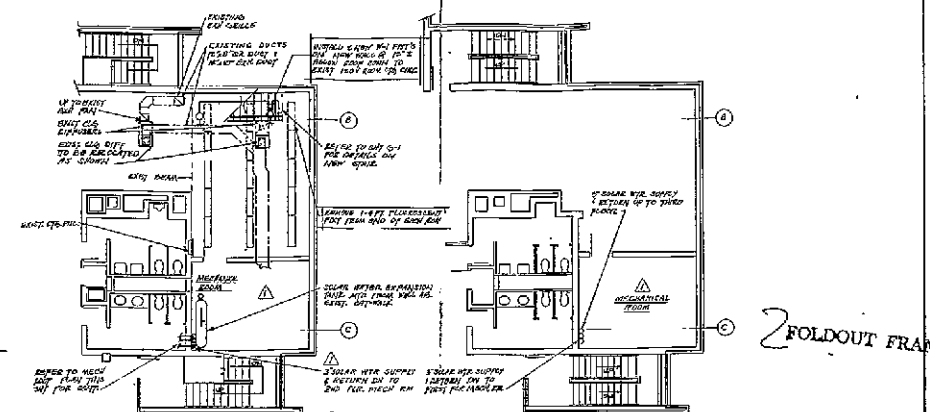


102-78 AS-BUILT
80-B

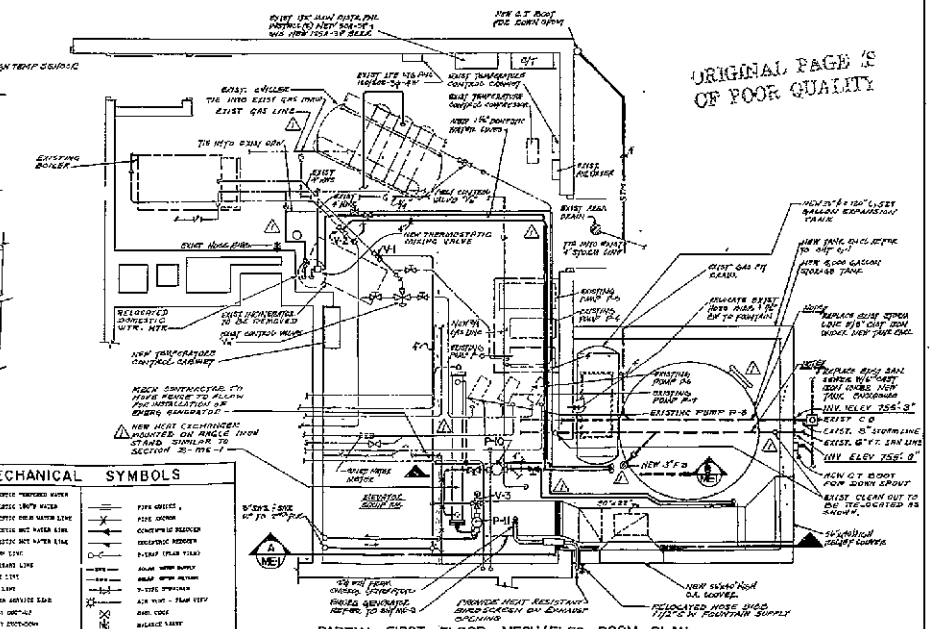
HIGHLIGHTS BUILDING SOLAR ENERGY PROJECT FOR THE COLUMBIA GAS SERVICE CORPORATION DIST. 77-98 COLUMBUS, OHIO		JOB NO. 7800-B-0 DATE REPT. 10/1/78 SHEET 01 OF 01
H. A. Williams and Associates, Inc. CONSULTING ENGINEERS 301 WEST FRENCHES ROAD COLUMBUS, OHIO 43204		G-2



- 1. RECOMMEND ROUTE TO RUN WITH PIPES AS NEAR AS POSSIBLE IN FIGHT FOR EACH ROOM
- 2. RUN ALSO NOTER GIVES LEVEL
- 3. WARE TO BE INTERFERED IN ACCORDANCE WITH ALL LOCAL CODES
- 4. PHYSICAL LAYOUT IS ONLY SUGGESTIVE, EXACT LOCATION OF PIPES TO BE COORDINATED WITH STRUCTURAL STAFF
- 5. KEEP IN MIND G & E FOR EXACT LOCATION OF COLLECTORS




PARTIAL SECOND FLOOR MECH/ELEC. PLAN
SCALE 1/8"=1'-0"



PARTIAL FIRST FLOOR MECH/ELEC. ROOM PLAN

[illegible]

ORIGINAL PAGE IS
OF POOR QUALITY



HIGHLIGHTS BUILDING
SOLAR ENERGY PROJECT
for
THE COLUMBIA GAS SERVICE CORPORATION
DIST 77-98 COLUMBUS, OHIO

H. A. Williams and Associates, Inc.
CONSULTING ENGINEERS
980 WEST HENDERSON ROAD COLUMBUS, OHIO 43220

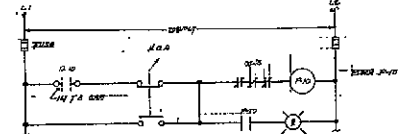
JOB
NO 76008-01
DATE (SEPT 20 1977)
SET OF 6

ME-I

NOTE: FIXTURE NUMBER, LETTER PREFIX INDICATES TYPE OF MOUNTING AS FOLLOWS:
 CL-CEILING MOUNTED; S-STEN SUSPENDED; W-WALL MOUNTED; R-CEILING RECESSED; WR-WALL RECESSED;
 CV-COVE MOUNTED; UC-UNDER CABINET; RF-ROOF MOUNTED; P-POST; GR-GROUND MOUNTED; H-MOUNTED IN HOOD

[illegible]

ELECTRICAL LEGEND		
ALL SYMBOLS ARE IN ACCORDANCE WITH THE		INDICATED BY THE CONTRACTOR
TERMINOLOGY		UNLESS OTHERWISE NOTED
○	GROUND SYMBOL	
○	WALL OUTLET	SEE DRAWINGS
○	EXTERIOR OUTLET, AS SHOWN	
○	VEHICLE JOINTING BOX	SEE DRAWINGS
○	CEILING HOOKOUT BOX	
○	CEILING RECESSED, 3 INCH DIA. TYPE	3"
○	CEILING RECESSED, 4 INCH DIA. TYPE	4"
○	POULIC INTRIC - WIRELESS LAMP	20"
○	POULIC INTRIC - 1/2 INCH, 3 INCH & 4 INCH	
○	TELEPHONE OUTLET	14"
○	POULIC TELEPHONE OUTLET	14"
○	ELECTRIC PANEL	6-1/2" X 10"
○	WALL MOUNTED - 4" WIDE	4" MOUNTING
○	WALL MOUNTED - 3" WIDE	4" MOUNTING
○	V-10 OUTLET	25"
○	WALL MOUNT - 10 INCH	10"
○	ALLUM OUTLET BOX	SEE DRAWINGS
○	ALL IN, 1/2 INCH WIDE, 1/2 INCH DIA. TYPE	20" MOUNTING
○	WALL MOUNTED - 1/2 INCH	1/2"
○	WALL MOUNTED, 1/2 INCH DIA. TYPE	1/2"
○	WALL MOUNTED, 1/2 INCH DIA. TYPE	1/2"

[illegible]

NOTE: NO
F.O.I. REQUEST
SINCE DE
TEMPERATURE
FINDS ARE
NOT 45-2

KEY COMB - COMBINATION MAGNETIC ACROSS THE LINE,
MAN. - MANUAL, MAG - MAGNETIC ACROSS-THE LINE, S.D - STAR DELTA;
A.T - AUTO TRANSFORMER, C.Y - CONTROL TRANSFORMER; H.O.A - HAND-OFF AUTO SELECTOR
SWITCH, P - PILOT LIGHT; S.B. - START STOP PUSHBUTTONS, ON-OFF-ON OFF MAINTAINED
CONTACT ELECTRIC SWITCH, H.A - HAND AUTO SELECTOR SWITCH

SOLAR ENERGY PROJECT
for

JDB
 NO 76008-DI
 DATE SEPT 20, 1970
 SET OF 6

A453

LINE DIAGRAM OF EMERGENCY POWER SYSTEM

83-A

83-6

1) ADD TDM-1	12-28-74	WJS	HONEYWELL INC TCP-1 CENTRAL Bldg (Loop) HANFORD Bldg COLUMBIA GAS G 2200 W. FIFTH AVE
2) DMS UPDATE	7-21-74	NJS	
3) ADD R. DRIVER, CHANGE R1	6-1-74	NJS	
4) DRAWING UPDATE	06-7-75	NJS	
Excluded	Date	App	
Prepared by	Drawn On	Date	10-31-71
Reviewed by	Approved On	Sheet	2 Of 2
		PLANT NO	95177060

APPENDIX F.

ACCEPTANCE TEST PLAN

84-A

Columbia Gas/Highlights Building Solar Energy System

Acceptance Test Plan

INDEX

I. Solar System Conformance to Installation Specifications	85
II. Solar System Operation Tests	86
A. Solar Collectors	
B. Solar Heat Exchanger	
C. Domestic Hot Water Heat Exchanger	
D. Solar Collector Loop Pump	
E. Solar Storage Loop Pump	
F. Solar System Controls	
III. Solar System Safeties Tests	93
A. Solar Collector High Temperature Safety	
B. Solar Collector Over Travel Safety	
C. Solar Collector High Wind Safety	
D. Solar Collector Loop Flow Safety	
E. Solar Collector Loop High Temperature Safety	
F. Solar Collector Loop High Pressure Safety	
G. Solar Storage Loop High Pressure Safety	
H. Electrical Power Interruption Safety	
I. Other Safeties	

SECTION I

SOLAR SYSTEM CONFORMANCE TO INSTALLATION SPECIFICATIONS

The first phase of the Highlights Building solar energy system acceptance test included an evaluation of the materials and workmanship used during construction. This evaluation was conducted in order to establish material and workmanship conformance with the Installation Specifications for the project and compliance with the Highlights Building solar energy system project construction drawings. This phase of the Highlights Building solar energy system acceptance test has been completed.

Columbia retained an independent agency, H. A. Williams and Associates, Consulting Engineers, to review all manufacturers' drawings and shop drawings for all materials provided for the solar energy system. During their reviews H. A. Williams rejected numerous manufacturers' drawings and shop drawings for non-conformance with the Installation Specifications. The Installation Specifications are part of the contract documents for the construction contract between Columbia Gas and Sauer, Inc., the construction prime contractor. Manufacturers' drawings and shop drawings for solar system materials that were not in compliance were revised and resubmitted, as required, until conformance with the Installation Specifications was reached. H. A. Williams has maintained a file of all rejected and accepted drawings for the solar system materials.

During construction, weekly inspections of materials delivered to the construction site and inspections of the workmanship at the site were conducted by H. A. Williams and Columbia Gas. These inspections were conducted to insure that the construction was in conformance with the Installation Specifications for the project and in compliance with the Highlights Building solar energy project construction drawings. Additionally, the Department of Energy Contract Officers Representative conducted several evaluations at the site during construction.

SECTION II

SOLAR SYSTEM OPERATION TESTS

The Highlights Building solar energy acceptance test will include a test of the solar system under operating conditions. This section outlines the solar system items to be tested, the solar system performance requirements, and the method of test. Columbia has retained an independent agency, H. A. Williams and Associates, Consulting Engineers, to observe the operation tests and assure the solar system compliance with the performance requirements. Additionally, the Department of Energy Contract Officer's Representative will be informed prior to all operation tests.

A. Solar Collector Operation - Each individual solar collector row must demonstrate the ability to track the sun automatically for all direct radiation levels throughout the range of 100 BTU/hr-sq. ft. to 350 BTU/hr-sq. ft. The method of test will be to observe the ability of the solar collectors to focus the solar radiation on the absorber tube. These operation tests will be conducted on five different days, not necessarily consecutive, in which the direct solar radiation is 100 BTU/hr-sq. ft. or greater for not less than four consecutive hours. Observations will be made at 15 minute intervals throughout the test period of each of the five days.

The efficiency of the entire solar collector array will be measured on five different days, not necessarily consecutive, in which the direct solar radiation is 100 BTU/hr-sq. ft. or greater for not less than four consecutive hours. For purposes of testing, the solar collector inlet and outlet temperatures and the incident solar energy rate will be taken as the average of the readings taken at the beginning and end of a 15 minute interval, i.e.

I_{Avg} = Average direct normal solar radiation for 15 minute test interval. (BTU/hr-sq. ft.)

I_i = Direct normal solar radiation at beginning of 15 minute test interval. (BTU/hr-sq.ft.)

I_f = Direct normal solar radiation at end of 15 minute test interval. (BTU/hr-sq. ft.)

$$I_{Avg} = \frac{I_i + I_f}{2}$$

$$T_{\text{Avg Inlet}} = \frac{T_{\text{Inlet, i}} + T_{\text{Inlet, f}}}{2}$$

where:

$T_{\text{Avg Inlet}}$ = Average temperature of fluid entering collector array (°F)

$T_{\text{Inlet, i}}$ = Temperature of fluid entering collector array at beginning of 15 minute test interval. (°F)

$T_{\text{Inlet, f}}$ = Temperature of fluid entering collector at end of 15 minute test interval. (°F)

$$T_{\text{Avg Outlet}} = \frac{T_{\text{Outlet, i}} + T_{\text{Outlet, f}}}{2}$$

where:

$T_{\text{Avg Outlet}}$ = Average temperature of fluid leaving collector array (°F)

$T_{\text{Outlet, i}}$ = Temperature of fluid leaving collector array at beginning of 15 minute test interval (°F)

$T_{\text{Outlet, f}}$ = Temperature of fluid leaving collector array at end of 15 minute test interval (°F)

The efficiency of the solar collector array for each 15 minute test interval will be calculated from

$$\eta = \rho \dot{Q} C_p \frac{(T_{\text{Avg Outlet}} - T_{\text{Avg Inlet}})}{A I_{\text{Avg}}}$$

where:

ρ = density of solar collector loop fluid

\dot{Q} = volumetric flow rate of solar collector loop fluid

C_p = specific heat of solar collector loop fluid

A = solar collector aperture area

During these tests the minimum average value of I_{Avg} shall be 100 BTU/hr-sq.ft.

Also during the 15 minute interval the solar collector loop volumetric flow rate must remain steady at 75.0 gallons per minute \pm 1.0 gpm.

B. Solar Heat Exchanger Operation - The design maximum heat transfer rate of the solar heat exchanger is 600,000 BTU/hr and the design heat exchanger effectiveness is 60%.

The solar heat exchanger effectiveness will be determined by measuring the temperature of the fluid entering and leaving the solar heat exchanger from the solar collector loop and the temperature of the fluid entering and leaving the solar heat exchanger from the solar storage loop. The heat exchanger effectiveness will be determined from the equation:

$$\epsilon = \frac{C_{\text{hot}} (T_{\text{hot, in}} - T_{\text{hot, out}})}{C_{\text{min}} (T_{\text{hot, in}} - T_{\text{cold, in}})}$$

or alternatively:

$$\epsilon = \frac{C_{\text{cold}} (T_{\text{cold, out}} - T_{\text{cold, in}})}{C_{\text{min}} (T_{\text{hot, in}} - T_{\text{cold, in}})}$$

where:

$T_{\text{hot, in}}$ = Temperature of fluid entering solar heat exchanger from solar collectors (°F)

$T_{\text{hot, out}}$ = Temperature of fluid leaving solar heat exchanger and returning to solar collectors (°F)

$T_{\text{cold, in}}$ = Temperature of fluid entering solar heat exchanger from solar storage (°F)

$T_{\text{cold, out}}$ = Temperature of fluid leaving solar heat exchanger and returning to solar storage (°F)

C_{hot} = Hot fluid capacity rate (BTU/hr - °F)

C_{cold} = Cold fluid capacity rate (BTU/hr - °F)

C_{min} = the smaller of the C_{hot} and C_{cold} magnitudes.

During the solar heat exchanger effectiveness measurement the solar collector loop volumetric flow rate must be maintained at 75.0 gpm \pm 1.0 gpm and the solar storage loop volumetric flow rate must be maintained at 95.0 gpm \pm 1.0 gpm

C. Domestic Hot Water Heat Exchanger Operation - The design heat transfer rate of the domestic hot water heat exchanger is 345,000 BTU/hr. with 40°F entering water temperature, 180°F storage tank temperature and with a domestic hot water flow rate of 6.9 gpm.

The actual heat transfer rate of the domestic hot water heat exchanger will be determined by heating the solar energy storage tank to 180°F, adjusting the domestic hot water flow rate to 6.9 gpm + 0.1 gpm and measuring the temperature of the water entering the domestic hot water heat exchanger and the temperature of the water leaving the domestic hot water heat exchanger. The actual heat transfer rate will be determined from the equation:

$$q = \frac{(60 \text{ min})}{(\text{hr})} \cdot \frac{(231 \text{ cu. in.})}{(\text{gal.})} \cdot \frac{(\text{cu. ft.})}{(1728 \text{ cu. in.})} \rho \dot{Q} C_p (T_{\text{Outlet}} - T_{\text{Inlet}})$$

$$\text{or } q = 8.02 \rho \dot{Q} C_p (T_{\text{outlet}} - T_{\text{inlet}})$$

where:

q = heat transfer rate (BTU/hr)

ρ = density of domestic hot water (lb/cu ft)

\dot{Q} = volumetric flow rate (gpm)

C_p = specific heat of domestic hot water (BTU/lb °F)

T_{inlet} = temperature of water entering the domestic hot water heat exchanger (°F)

T_{outlet} = temperature of water leaving the domestic hot water heat exchanger (°F)

D. Solar Collector Loop Pump Operation - The solar collector loop pump is a Thrush Model 2 TV-2-L. The impeller on the pump has been trimmed to a 7-5/16" diameter to deliver 75 gpm against a head of 50 feet. The pump was selected to deliver design capacity when operating with a 44% by volume Dowtherm SR-1 and 56% by volume water solution.

The method of test will be to increase the discharge pressure on the pump until the volumetric flow rate decreases to 75.0 ± 1.0 gpm. When a flow rate of 75.0 gpm is established the pump power and current will be measured. The current for the three phase pump motor should not exceed 6.8 amps per phase at 75.0 gpm. Additionally, the discharge pressure of the pump will be measured with a 75.0 gpm flow rate to determine the operating point on the pump performance map.

E. Solar Storage Loop Pump Operation - The solar storage loop pump is a Thrush Model 2 TV-2-L. The impeller on the pump has been trimmed to 7-5/16 inch diameter to deliver 95 gpm against a 45 foot head. The pump was selected to deliver design capacity operating with water.

The method of test will be to increase the pump discharge pressure until the volumetric flow rate decreases to 95.0 ± 1.0 gpm. When a flow rate of 95.0 gpm has been established the pump power and current will be measured. The current for the three phase pump motor should not exceed 6.8 amps per phase at 95.0 gpm. Additionally, the discharge pressure of the pump will be measured with a 95.0 gpm flow rate to determine the operating point on the pump performance map.

F. Solar System Controls Operation - Tests will be conducted to establish that the solar system controls are capable of selecting the proper mode for the solar system based on the state of the prevailing conditions. There are five different two-position automatic controllers and one two-position manual control for the solar system. The manual control is a Heating/Cooling master controller that resets the control points of another controller. The prevailing conditions to which the automatic controllers respond are as follows:

H = Total solar radiation on a surface tilted at 40° to the horizontal (BTU/hr-sq. ft.)

T1 = T3 = Solar Collector loop fluid temperature at the inlet to the solar heat exchanger ($^\circ\text{F}$)

T2 = T5 = Solar energy storage tank temperature ($^\circ\text{F}$)

In all there are 32 possible winter heating modes and 32 possible summer cooling modes. However, the control system has built in interlocks which prevent undesirable modes of system operation. The allowed number of system operating modes is 36 (18 space heating modes and 18 space cooling modes). These 36 modes are listed in Tables 1 and 2.

The method of test will be to systematically exercise the solar system controllers by providing all of the 36 combinations of temperatures, solar radiation, and position of the heating/cooling manual control. With these 36 combinations of conditions, the control system will be checked to determine if the solar system component status and solar system status is as prescribed in Tables 1 and 2.

SPACE HEATING MODES

System Mode	PREVAILING CONDITIONS					SYSTEM STATUS		SYSTEM COMPONENT STATUS			
	H > 125	T3 > 80F	T1 > T2	T5 > 150F	T5 > 230F	Solar Energy To Storage	Building Heat Source	Solar Collector Position	Collector Loop Pump	Storage Loop Pump	H.X. Bypass Valve Position
H-S-1	Yes	Yes	Yes	Yes	Yes	No	Solar	Down	On	On	H.X.
H-S-2	Yes	Yes	Yes	Yes	No	Yes	Solar	Up	On	On	H.X.
H-S-3	Yes	Yes	Yes	No	No	Yes	Boiler	Up	On	On	H.X.
H-S-4	Yes	Yes	No	Yes	Yes	No	Solar	Down	On	Off	H.X.
H-S-5	Yes	Yes	No	Yes	No	No	Solar	Up	On	Off	H.X.
H-S-6	Yes	Yes	No	No	No	No	Boiler	Up	On	Off	H.X.
H-S-7	Yes	No	No	Yes	Yes	No	Solar	Down	On	Off	Bypass
H-S-8	Yes	No	No	Yes	No	No	Solar	Up	On	Off	Bypass
H-S-9	Yes	No	No	No	No	No	Boiler	Up	On	Off	Bypass
H-NS-1	No	Yes	Yes	Yes	Yes	No	Solar	Down	Off	Off	H.X.
H-NS-2	No	Yes	Yes	Yes	No	No	Solar	Down	Off	Off	H.X.
H-NS-3	No	Yes	Yes	No	No	No	Boiler	Down	Off	Off	H.X.
H-NS-4	No	Yes	No	Yes	Yes	No	Solar	Down	Off	Off	H.X.
H-NS-5	No	Yes	No	Yes	No	No	Solar	Down	Off	Off	H.X.
H-NS-6	No	Yes	No	No	No	No	Boiler	Down	Off	Off	H.X.
H-NS-7	No	No	No	Yes	Yes	No	Solar	Down	Off	Off	Bypass
H-NS-8	No	No	No	Yes	No	No	Solar	Down	Off	Off	Bypass
H-NS-9	No	No	No	No	No	No	Boiler	Down	Off	Off	Bypass

TABLE 1. SPACE HEATING MODES

COLUMBIA/HIGHLIGHTS BUILDING SOLAR ENERGY PROJECT

SPACE COOLING MODES

System Mode	PREVAILING CONDITIONS					SYSTEM STATUS		SYSTEM COMPONENT STATUS			
	H > 125	T3 > 80F	T1 > T2	T5 > 190F	T5 > 230F	Solar Energy To Storage	Building Cooling Source	Solar Collector Position	Collector Loop Pump	Storage Loop Pump	H.X. Bypass Valve Position
C-S-1	Yes	Yes	Yes	Yes	Yes	No	Solar	Down	On	On	H.X.
C-S-2	Yes	Yes	Yes	Yes	No	Yes	Solar	Up	On	On	H.X.
C-S-3	Yes	Yes	Yes	No	No	Yes	Boiler	Up	On	On	H.X.
C-S-4	Yes	Yes	No	Yes	Yes	No	Solar	Down	On	Off	H.X.
C-S-5	Yes	Yes	No	Yes	No	No	Solar	Up	On	Off	H.X.
C-S-6	Yes	Yes	No	No	No	No	Boiler	Up	On	Off	H.X.
C-S-7	Yes	No	No	Yes	Yes	No	Solar	Down	On	Off	Bypass
C-S-8	Yes	No	No	Yes	No	No	Solar	Up	On	Off	Bypass
C-S-9	Yes	No	No	No	No	No	Boiler	Up	On	Off	Bypass
C-NS-1	No	Yes	Yes	Yes	Yes	No	Solar	Down	Off	Off	H.X.
C-NS-2	No	Yes	Yes	Yes	No	No	Solar	Down	Off	Off	H.X.
C-NS-3	No	Yes	Yes	No	No	No	Boiler	Down	Off	Off	H.X.
C-NS-4	No	Yes	No	Yes	Yes	No	Solar	Down	Off	Off	H.X.
C-NS-5	No	Yes	No	Yes	No	No	Solar	Down	Off	Off	H.X.
C-NS-6	No	Yes	No	No	No	No	Boiler	Down	Off	Off	H.X.
C-NS-7	No	No	No	Yes	Yes	No	Solar	Down	Off	Off	Bypass
C-NS-8	No	No	No	Yes	No	No	Solar	Down	Off	Off	Bypass
C-NS-9	No	No	No	No	No	No	Boiler	Down	Off	Off	Bypass

TABLE 2. - SPACE COOLING MODES

SECTION III

SOLAR SYSTEM SAFETIES TESTS

The Highlights Building solar energy acceptance test will include a test of all of the safeties for the system. This section outlines the solar system safeties to be tested, the operational requirements and the method of test. Columbia has retained an independent agency, H. A. Williams and Associates, Consulting Engineers, to observe the testing of the system safeties and to assure that the system safeties are operating as specified in the Installation Specifications. Additionally, the Department of Energy Contract Officers Representative will be informed prior to tests of the system safeties. The following safeties will be tested.

A. Solar Collector High Temperature Safety - Each individual solar collector row has a temperature sensor on the absorber tube. In the event the absorber tube reaches a temperature of 260°F or greater, the unit controller for that collector row will return the row to the "stow" position. This safety prevents the Dowtherm SR-1 fluid in the primary loop from reaching temperatures at which decomposition of the fluid would occur. This safety would prevent an individual collector row that experienced a flow blockage from exceeding 260°F when the remainder of the total solar collector array might be operating at temperatures well below 260°F.

The method of test will be to block the flow in one collector row with the total array in operation. The temperature of the absorber tube of the collector row with no flow will be measured. The absorber temperature required to return that collector row to the "stow" position must be $260^{\circ} \pm 10^{\circ}\text{F}$. This test sequence will be repeated for each solar collector row.

B. Solar Collector Over Travel Safety - Each individual solar collector row has two top push roller switches that sense the end of the arc of normal travel by contacting cam lobes. One top push roller switch senses the end of the normal travel in the forward travel direction for the collector. The other top push roller switch senses the end of normal travel in the reverse travel direction.

Each individual solar collector row also has two over travel switches. The over travel switches are whisker switches that, in the event of a top push roller switch failure, sense when an individual collector has traveled past the end of the arc of normal travel. One whisker switch is used to sense over travel in the forward travel direction and another whisker switch detects over travel in the reverse travel direction of the collector.

The method of test will be to check the operation of both whisker switches for all rows. For one row of solar collectors at a time, the cam lobes for the top push roller switches will be moved in order to defeat the normal travel control. The solar collector row will then be powered in the forward direction. The forward over travel whisker switch must contact the solar collector panel and stop the drive motor. The same solar collector row will then be powered in the reverse direction. The reverse over travel whisker switch must contact the solar collector panel and stop the drive motor. The same method of test will be applied to each individual row of collectors.

C. Solar Collector High Wind Safety - The single axis tracking solar collectors have a safety to prevent damage to the solar collectors that might occur with extremely high winds. With wind speeds of approximately 90 mph and with the solar collectors tilted at a maximum angle of 63° to the horizontal (which occurs on December 22nd) there is a potential for permanently distorting or breaking the solar collectors.

The solar system field controller has a WeatherMeasure Model W161 wind control that senses the wind speed and (through associated logic circuits) will return the entire collector field to the "stow" position. The "stow" position for the solar collectors is a horizontal position where the wind drag is less.

The method of test will be to adjust the wind speed controller set point below the ambient wind speed and observe if the solar collector field is driven to the "stow" position.

D. Solar Collector Loop Flow Safety - With the 40 to 1 concentration ratio of this solar collector, it is necessary to have flow in the absorber tube to prevent temperatures from exceeding the 280°F maximum working temperature of the Dowtherm SR-1/water solution. Therefore, the solar collector loop has a safety system that prevents the solar collectors from tracking the sun when the solar collector loop pump is not producing pressure and flow.

The method of test for the safety system will be to simulate a solar collector loop pump failure by turning the solar collector loop pump off. The Honeywell differential pressuretrol unit that is installed across the solar collector loop pump must sense the loss of pressure differential and automatically return the entire solar collector field to the "stow" position.

E. Solar Collector Loop High Temperature Safety - Under normal operating conditions the Highlights Building Solar Energy System controls will turn the solar collectors away from the sun when the solar energy storage tank is "full". That is, after the solar energy storage tank reaches approximately 230°F, the control system will turn the solar collectors to the stow position. Besides this normal temperature control on the storage tank, the solar collector loop also has a safety circuit that prevents the Dowtherm SR-1 fluid from reaching temperatures at which decomposition of the fluid would occur. In the event the solar collector loop temperature reaches 250°F the solar collector temperature safety will return the solar collectors to the stow position.

The method of test will be to turn the solar collector loop pump on. The solar collectors will be allowed to track the sun and collect energy and no energy will be removed from the solar collector loop flow. The temperature of the closed solar collector loop fluid will increase. At the point the solar collector loop temperature reaches 250°F + 10°F the solar collector temperature safety must return the solar collector field to the stow position.

F. Solar Collector Loop High Pressure Safety - The solar collector loop for the Highlights Building solar energy system has a Watts No. 174A, 3/4-inch relief valve. The valve is ASME rated and approved. The valve construction features a bronze body with non-metallic disk-to-metal seating. The pressure relief set point is 60 psi and the valve has a National Board Certified Rating of 1,100,000 BTU steam discharge capacity.

The method of test will be to slowly pressurize the solar collector loop using a compressed air pressure supply and pressure regulator. The pressure at which the pressure relief valve starts to discharge water will then be measured with a calibrated pressure gauge.

G. Solar Storage Loop High Pressure Safety - The solar storage loop for the Highlights Building solar energy system has two Watts No. 174A, 3/4-inch relief valves. One relief valve is located on the solar energy storage tank and the other relief valve is located in the solar storage loop plumbing adjacent to the heat exchanger. Both valves are ASME rated and approved and have bronze body construction with non-metallic disk-to-metal seating. Both pressure reliefs are set at 30 psi and each valve has a National Board Certified Rating of 650,000 BTU steam discharge capacity.

The method of test will be to slowly pressurize the solar storage loop using a compressed air pressure supply and a pressure regulator. The pressure at which the first pressure relief valve starts to discharge will be determined with a calibrated pressure gauge.

H. Electrical Power Interruption Safety - The Highlights Building solar energy installation has a 40 to 1 concentration ratio collector. If the solar collector is focused on the sun and collecting energy, it is necessary to have flow in the absorber tube to prevent the temperature of the Dowtherm SR-1 collector loop fluid from exceeding its 280°F maximum working temperature. In the event of an electrical power failure the flow in the solar collector loop would stop. Therefore, a standby electric generating system was installed to provide electric power to power the solar collector loop pump and to power the solar collectors to the stow position in the event of a electric power failure.

The standby electric generating system will be tested by throwing a main power breaker for the building to the "off" position. The automatic load transfer control must sense the loss of power, start the standby electric generator, and automatically switch the electrical load of the solar collector loop pump and the solar collector motors to the electric generator. The main power breaker will then be returned to the "on" position. The automatic load transfer control must sense the return of normal building electrical power, switch the electrical load of the solar collector loop pump and the solar collector motors back to normal building electric power, and turn off the standby electric generator.

I. Other Solar System Safeties - The Highlights Building solar energy system has several other safety features. Guardrails have been welded in places around the edges of the roof where people may walk. Safety belts and sunglasses have been provided for all solar collector maintenance personnel.

Temperatures of 500°F were measured on surfaces near the focal point of the solar collector. These areas have all been insulated and shielded with highly reflective material. Surface temperatures have been reduced to a much safer temperature of 150°F maximum.

Electric motors are protected from electrical overload using standard methods. The gas fired boiler has built in safeties per AGA and ANSI standards.

APPENDIX G.

SOLAR COLLECTOR PANEL DAMAGE ANALYSIS

9b-A

APPENDIX G.

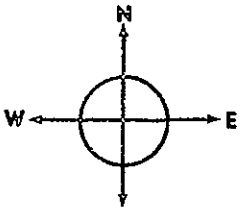
SOLAR COLLECTOR PANEL DAMAGE ANALYSIS

The parabolic solar reflectors were fabricated by Hexel Corporation with a 0.020 inch aluminum sheet adhesively bonded on both sides of an expanded aluminum honeycomb core. Honeywell reinforced the parabolic shape with expanded aluminum honeycomb braces or "strongbacks" as shown on Figure 10, page 27. These stiffening ribs were permanently mounted with epoxy adhesive, but were positioned and held in place by aluminum angle and screw fasteners until the epoxy set. Water penetrated the back side of the solar reflectors through these screw fastener holes and entered the expanded honeycomb cell structure.

During the winter of 1978-1979, the first winter of operation, the panels were exposed to a series of freeze-thaw cycles. The water trapped in the honeycomb cell structure expanded upon freezing and pushed the 0.020 inch aluminum surface out on the reflector (concave) side of the aluminum panel. The aluminum skin separated from the aluminum honeycomb causing a "bump" or "blister" on the reflector surface. As more freeze-thaw cycles occurred, additional moisture would penetrate adjacent cells exposed by the blister. Table 5 presents details on the location, number and size of the blisters on all 44 reflector panels.

During the summer of 1979, Columbia caulked and sealed all of the screw holes in the reflector panels and painted the surfaces of the strongback and the adjacent surfaces on the backside or convex side of the parabolic panel. This procedure

REFLECTOR DISTORTION SIZE & LOCATION



	West Panel	West Center Panel	East Center Panel	East Panel
Row 11	none	FS	none	FS
Row 10	FS	FS	SS + 1 ea long narrow	1 ea long narrow
Row 9	FS	FS	SS	SS
Row 8	none	3 ea long narrow	1 ea long narrow	1 ea 7" dia.
Row 7	3 ea long narrow	SS + edge distortion	1 ea long narrow edge distortion	FS
Row 6	8 ea 6-10" dia.	SS	1 ea 3" dia.	SS
Row 5	3 ea long narrow	SS	SS	1 ea 6" dia.
Row 4	SS	none	SS + edge distortion	1 ea long thin
Row 3	large distortions of top edge	FS	8 ea 3-4" dia.	SS
Row 2	none	4 ea 7-8" dia.	1 ea 7" dia.	FS
Row 1	large distortions of top edge	FS	none	SS

Key: SS = several small, more than 5 in number but generally less than 2 inches in diameter

FS = few small, 5 or less in number and all less than 2 inches in diameter

TABLE 5

has greatly retarded if not eliminated further panel damage during the winter of 1979-1980.

Each 16 foot long reflector panel at the Highlights Building solar installation is fabricated from two 8 foot long sections that are joined together into a single panel. This joint can be seen as the white line to the left of the blister shown in Figure 16 on page 50. Table 6 presents a histogram of panel surface area distortion for all of the 8 foot long sections of panel in each of the eleven collector rows, or a total of 88 panels. It has been calculated that the surface area of the reflector panel that has been permanently distorted by this freeze damage is approximately four-tenths of a percent of the total solar collector reflector surface.

REFLECTOR PANEL FREEZE DAMAGE HISTOGRAM

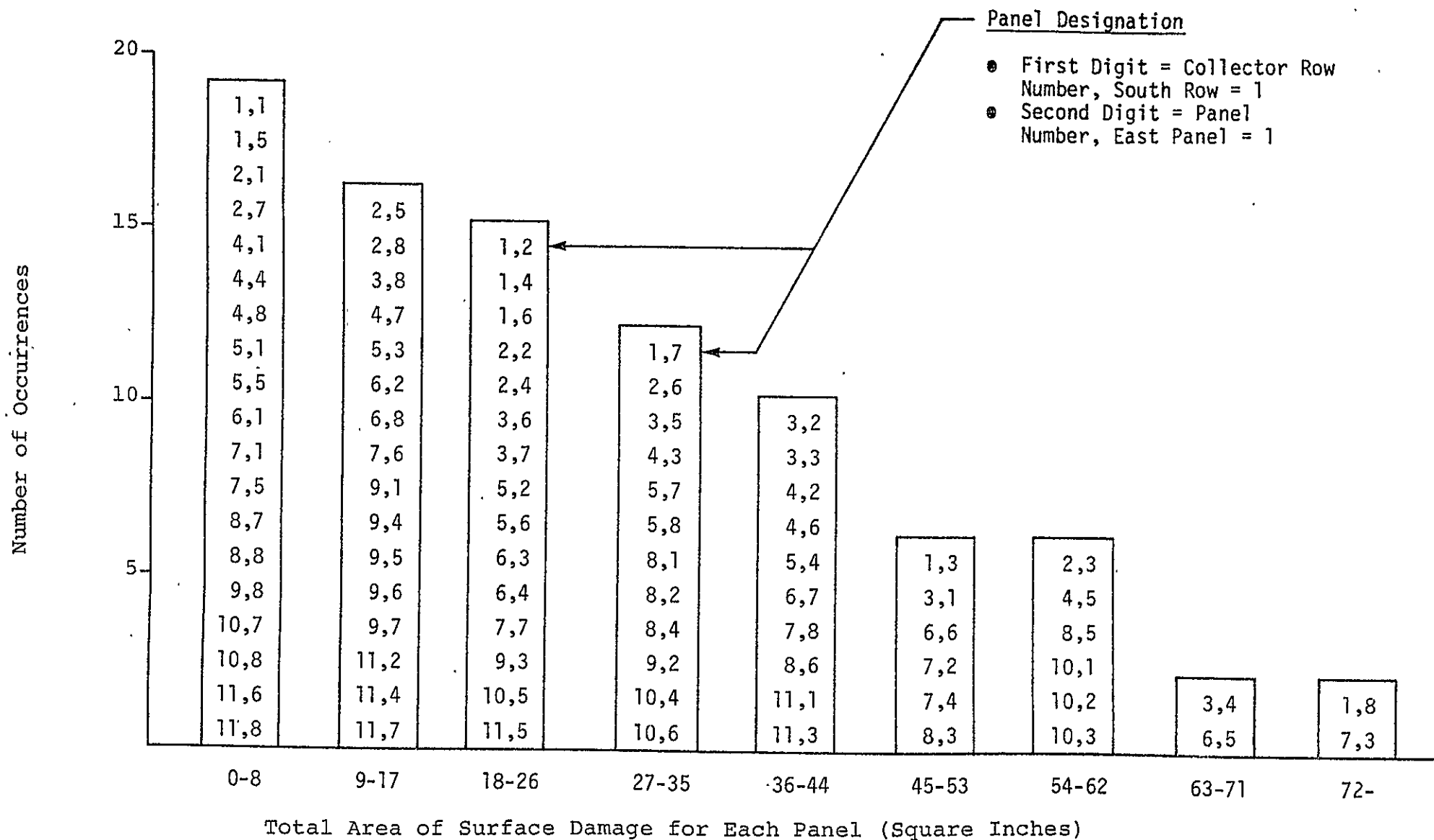


TABLE 6

APPENDIX H.

SOLAR COLLECTOR COUNTERWEIGHT SYSTEM DESIGN

APPENDIX H.

SOLAR COLLECTOR COUNTERWEIGHT SYSTEM DESIGN

It was determined visually that if the solar collector flux line was focused exactly on the absorber tube in the middle of each row then the flux line would be focused below the absorber tube at the ends of most of the collector rows. Columbia estimated the distributed torque on the torque tube from the geometry and weights of the Honeywell solar collector components. A 16 foot long solar collector panel is fastened to torque tube number 1 shown in Figure 25. A 9 inch long, 1-3/4 inch diameter, solid shaft extends through a support bearing and connects torque tube number 1 to torque tube number 2. Another 16 foot long solar collector panel is mechanically fastened to torque tube number 2. The following is the estimated total torque, T_{\max} .

	<u>Estimated Weight (Pounds)</u>	<u>Number Per Half Row</u>	<u>Estimated Distance to Centroid (Inches)</u>	<u>Torque (inch- pounds)</u>
Absorber Tube Assembly	72.4	2	46	6700
Reflector Panel	215.1	2	7.5	3200
Support Arms, tubes, insulation, etc.	8.3	2	24	<u>400</u>
Estimated Total Torque, T_{\max} =				10,300

TABLE H-1

Figure 25 presents the hypothesized state of torsion in the torque tubes and connecting shaft.

TORQUE TUBE TORSION

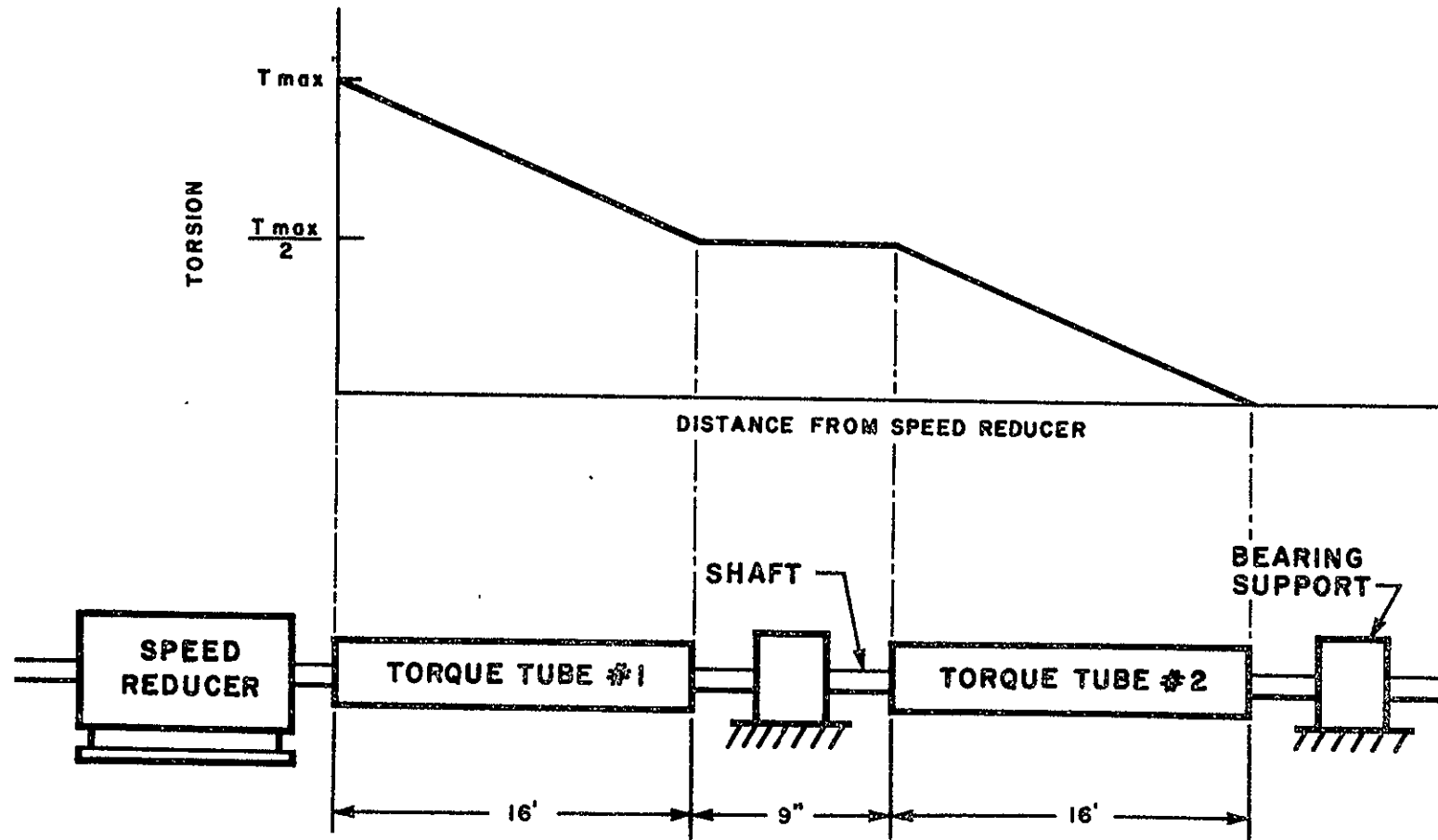


FIGURE 25

The following is an estimate of the angle of twist in the two torque tubes and the intermediate shaft. The analysis neglects the torsional stiffness of the reflector panels.

A. Angle of Twist - Torque Tube #1

$$\theta_1 = \int_0^{\ell} \frac{T(x) dx}{KG} \quad (1)$$

$$\theta_1 = \int_0^{\ell} \left[\frac{T_{\max}}{2} + \frac{T_{\max}}{2\ell} (\ell - x) \right] \frac{dx}{KG}$$

$$\theta_1 = \frac{T_{\max} \ell}{2KG} + \frac{T_{\max} \ell x}{2\ell KG} \Big|_0^{\ell} - \frac{T_{\max} x^2}{4\ell KG} \Big|_0^{\ell}$$

$$\theta_1 = \frac{T_{\max} \ell}{2KG} + \frac{T_{\max} \ell^2}{2\ell KG} - \frac{T_{\max} \ell^2}{4\ell KG}$$

$$\theta_1 = \frac{3 \cdot T_{\max} \ell}{4 KG} \quad (2)$$

Units:

θ_1 radians

T_{\max} inch-pounds

ℓ inches

G pounds per square inch

K Inches to the fourth power

For a hollow box section compute K as:

$$K = \frac{2tt_1 (a-t)^2 (b-t_1)^2}{at + bt_1 - t^2 - t_1^2} \quad \begin{array}{l} \text{(from reference 1 or} \\ \text{see reference 2 for an} \\ \text{alternative)} \end{array}$$

For this torque tube:

$$a = 4 \text{ inches}$$

$$b = 4 \text{ inches}$$

$$t = 1/8 \text{ inch}$$

$$t_1 = 1/8 \text{ inch}$$

$$K = 7.2732 \text{ in}^4$$

Now compute θ_1 , the angle of twist for torque tube #1:

$$\theta_1 = \frac{3 T_{\max} \ell}{4KG} \quad (2)$$

$$\theta_1 = \frac{(3) (10,300) (16) (12)}{(4) (7.2732) (12,000,000)}$$

$$\theta_1 = 0.0170 \text{ radians}$$

$$\theta_1 = \underline{0.974^\circ}$$

B. Angle of Twist - Intermediate Shaft

$$\theta_2 = \frac{T\ell}{GJ}$$

$$J = \frac{\pi d^4}{32} = \frac{(3.14) (1.75)^4}{32}$$

$$J = 0.9208$$

$$\theta_2 = \frac{(10,300) (9)}{(0.9208) (12,000,000)}$$

$$\theta_2 = 0.00839 \text{ radians}$$

$$\theta_2 = \underline{0.481^\circ}$$

¹ Formulas for Stress and Strain, Roark, page 196

² Advanced Mechanics of Materials, Seely and Smith -
2nd Edition, page 276

C. Angle of Twist - Torque Tube #2

$$\theta_3 = \int_0^{\ell} \frac{T(x) dx}{KG}$$

$$\theta_3 = \int_0^{\ell} \left[\frac{T_{\max} (\ell - x)}{2\ell} \right] \frac{dx}{KG}$$

$$\theta_3 = \left. \frac{T_{\max} \ell x}{2\ell KG} \right|_0^{\ell} - \left. \frac{T_{\max} x^2}{4\ell KG} \right|_0^{\ell}$$

$$\theta_3 = \frac{1}{4} \frac{T_{\max} \ell}{KG}$$

$$\theta_3 = \frac{(10,300) (16) (12)}{(4) (7.2732) (12,000,000)}$$

$$\theta_3 = 0.00566 \text{ radians}$$

$$\theta_3 = \underline{0.325^\circ}$$

D. Total Twist

Combining A, B and C Above:

$$\theta_{\tau} = \theta_1 + \theta_2 + \theta_3$$

$$\theta_{\tau} = 0.974^\circ + 0.481^\circ + 0.325^\circ$$

$$\theta_{\tau} = \underline{\underline{1.780^\circ}}$$

The effect of a total angle of twist ($\Delta\theta$) of 1.780° is shown in Figure 26. Note that the absorber tube position at the end of each solar collector row is shown to rotate (down) by an angle $\Delta\theta$. However the flux line rotates (down) by an angle $2 \Delta\theta$.

TORQUE TUBE TWIST

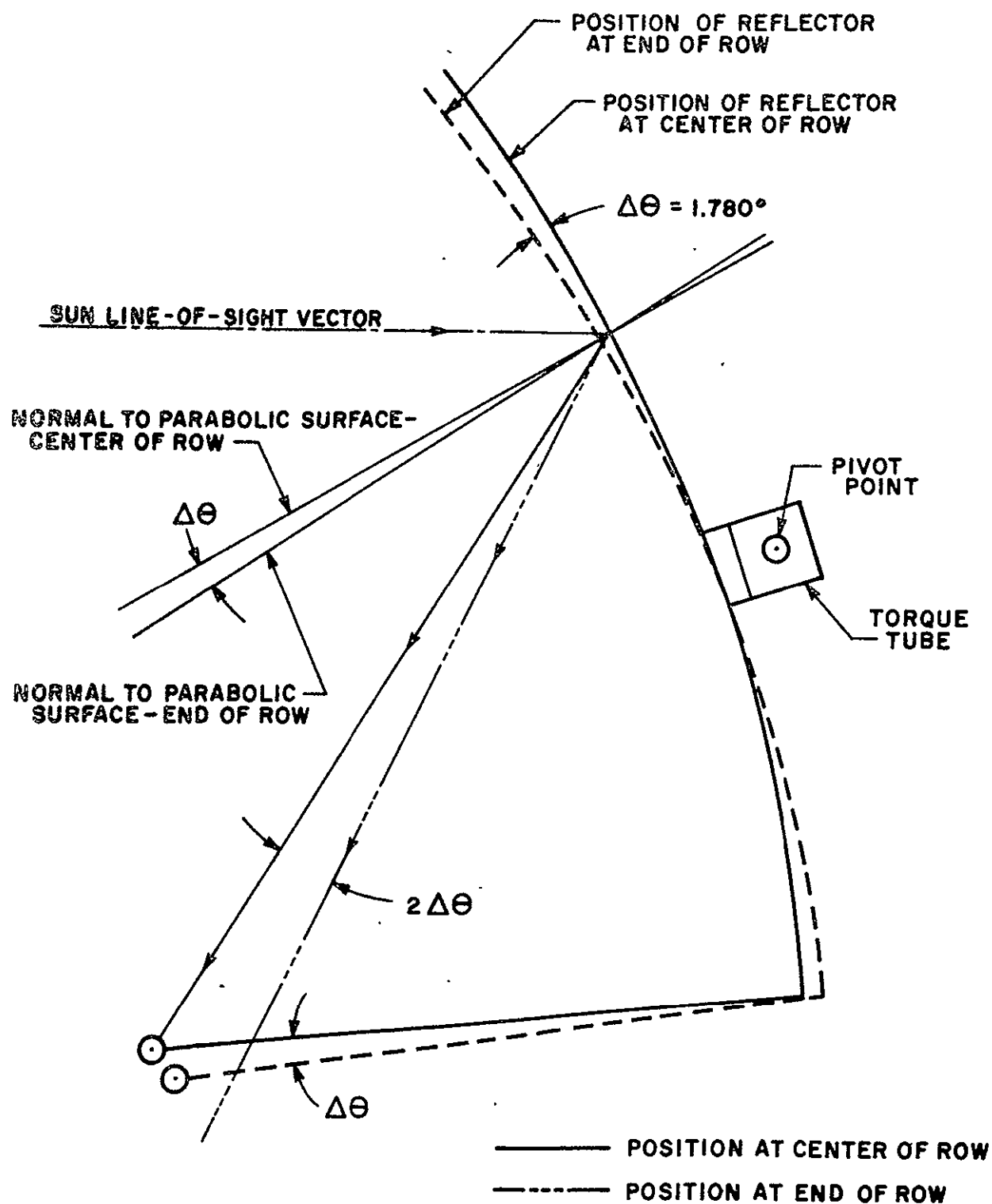


FIGURE 26

With this total angle of twist of the two torque tubes and the intermediate shaft, it can be seen from Figure 26 that if the flux line is focused exactly on the absorber tube in the middle of each row, none of the flux line will be focused on the absorber tube at the ends of the collector rows. From the geometry of the problem it is calculated that (given the center of the flux line on the center of the absorber tube in the middle of the row) the center of the flux line will be 1.50 inches below the center of the absorber tube at the end of each row. Since the diameter of the absorber tube is 1.25 inches, the center of the flux line will be 0.875 inches below even the bottom edge of the absorber tube at the end of each row.

The predicted droop of the flux line of 1.50 inches below the center of the absorber tube is very close to actual droop of the flux line measured in the field. Therefore, the assumption on page 103 (which neglects the torsional stiffness imparted by the reflector panel) may be reasonable.

A counterweight was designed to counteract the torque applied to the torque tubes by the solar collector panels and the absorber tube assemblies. To simplify fabrication an all steel counterweight was designed. Cheaper material alternatives exist for larger production quantities.

The counterweight includes a stack of 8 inch x 8 inch x $\frac{3}{4}$ inch hot rolled steel plates at the end of a $40\text{-}\frac{3}{8}$ inch long lever arm. The lever arm is fabricated from $2\text{-}\frac{1}{2}$ inch schedule 40 pipe welded to a metal U-clamp as shown in Figure 27, page 52. The dimensions of the counterweight are shown schematically on Figure 27. Each plate weights 13.5 pounds and the schedule

SOLAR COLLECTOR COUNTERWEIGHT DESIGN

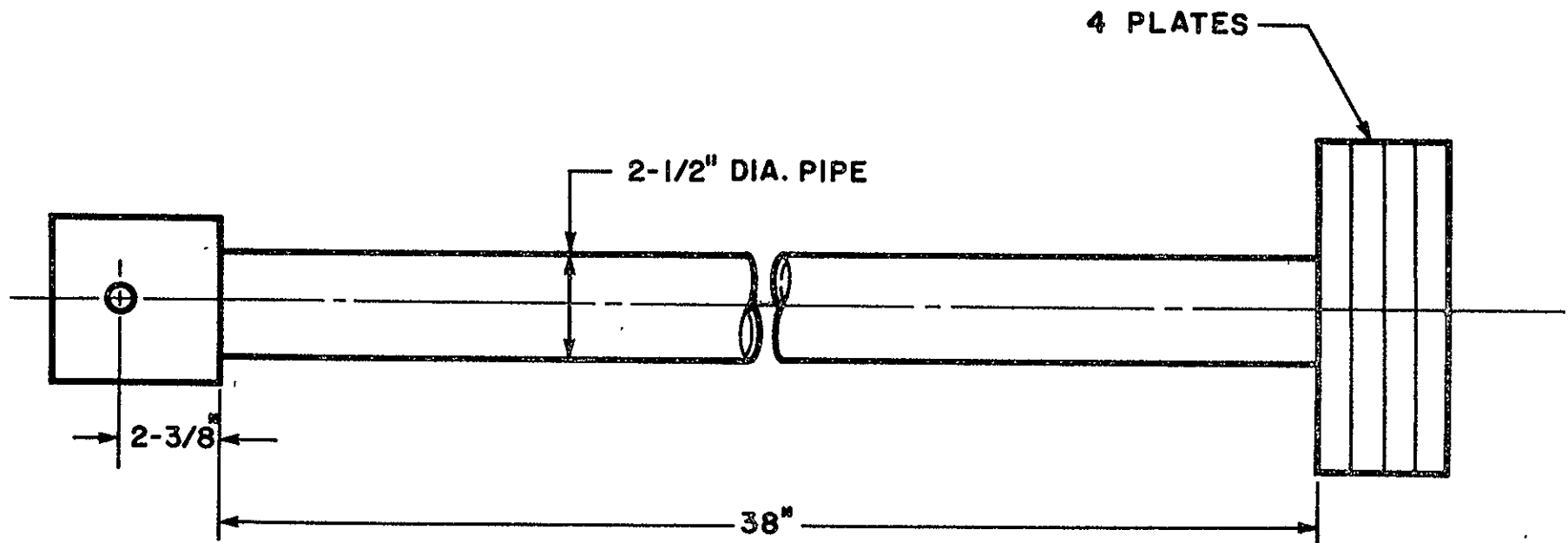


FIGURE 27

40 pipe weighs 11 pounds. The total moment exerted by each counterweight is 2500 inch-pounds when 4 steel plates are used.

Each solar collector row was retrofitted with six counterweights, three on each half row. This was done to distribute the counterweights in a manner equal and opposite to the distribution of the torsional loading of the solar collector absorber tubes and panels.

APPENDIX I.

SOLAR ENERGY UTILIZATION

10-9-A

APPENDIX I.

SOLAR ENERGY UTILIZATION

Columbia's technical proposal dated November 18, 1976 to U.S. DOE projected that the proposed solar energy system would collect 632 million BTU/year and utilize, i.e. deliver to the building loads, 569 million BTU/year. The building thermal demand was projected to be 1,728 million BTU/year, and the solar fraction was estimated to be 33 percent. The following is a discussion of the major elements of the solar energy system design and performance that affect seasonal solar energy utilization.

A. Building Thermal Load

Columbia's technical proposal, pages II-35, II-36 and II-37, projected the Highlights Building natural gas consumption to be 2,656 Mcf for the year 1976. From measurements of the Highlights natural gas boiler instantaneous efficiency it was estimated that the boiler seasonal efficiency was 65 percent. The building's annual thermal energy requirement was, therefore, estimated to be:

$$\begin{aligned} \text{Annual Thermal} &= 2,656,000 \times 1000 \times 0.65 \\ \text{Energy Requirement} &= 1,728 \text{ million BTU/year} \end{aligned}$$

The actual natural gas consumption in 1976 was 2710 Mcf (vis-a-vis estimated consumption of 2656 Mcf). However, for the reasons discussed in Section III, pages 8 and 9 of this report, the control schedule for the Highlights Building has been changed and the building natural gas consumption in 1979 was 4555 Mcf.

The current building annual thermal energy requirement is therefore estimated to be:

$$\begin{aligned} \text{Current Annual Energy Requirement} &= 4,555,000 \times 1000 \times 0.65 \\ &= 2,961 \text{ million BTU/year} \end{aligned}$$

B. Solar Collector Efficiency

Page II-9 of Columbia's technical proposal presents Honeywell's estimate of the Honeywell single axis tracking solar collector efficiency. Based on the temperature range of interest for the Highlights Building (200°F) and based on the Honeywell efficiency information provided in April of 1976 the solar collector instantaneous efficiency was estimated to be 70 percent of direct solar radiation. Seasonal solar collector efficiency was estimated to be 58 percent of direct solar radiation.

Actual efficiency of a Honeywell single-axis tracking solar collector was determined experimentally at Honeywell late in 1978. The measured peak efficiency of a single solar collector panel operating at 200°F was 64 percent of direct solar radiation. This efficiency is for a single solar collector panel with the absorber tube precisely hand adjusted and located at the focal point of the parabola, with fine tuning of the sun tracking electronics, with a clean absorber tube, with a clean cover glass, and with a clean FEK 244 reflector surface. Further, the solar collector efficiency testing does not include any heat losses for inlet and outlet plumbing to the solar collector absorber or for heat losses in the solar collector mains.

Detailed studies by Sandia Laboratories in Albuquerque, New Mexico and Jet Propulsion Laboratory show that the performance

of high concentration ratio reflecting surfaces and selective absorber coatings are affected and degraded by soiling. For example, specular reflectance of a reflecting surface can be reduced between 5 and 10 percent within a few months.

On any given day with direct solar radiation above 200 BTU/hr-sq. ft., the solar noon efficiency of the Highlights solar collector array will usually be between 48 and 52 percent, or 12 to 16 percent below the efficiency of a single solar collector panel on a test stand. This difference is probably fully accounted for by the combined effects of the following:

- Losses due to absorber tube dirt.
- Losses due to cover glass dirt.
- Losses due to reflector panel dirt.
- Normal thermal losses from solar collector inlet and outlet plumbing to each solar collector row and plumbing between panels within a row.
- Normal thermal losses from solar collector array field plumbing and mains.

None of the above items are present in a single day test of a single solar collector panel on a test stand. However, in an operating solar collector field all of these losses are present to some degree. Any one of the above items can represent some several percent of the difference in efficiency between a single solar panel and an operating solar collector array where the efficiency of the array is measured at the inlet and outlet heat transfer fluid mains at the boundary of the solar collector field.

C. Solar Radiation Availability

Columbia used solar radiation information for Columbus, Ohio that was available at the time the technical proposal was prepared. The beam solar radiation on a plane tilted at 40° was estimated to be 327,929 BTU/ft²-year. As presented in Section VIII, page 61 of this report, the actual direct solar radiation on a surface tilted at 40 degrees in Columbus, Ohio in 1979 was 262,063 BTU/ft²-year.

D. Solar System Losses

Based on computer simulations of the Highlights Building solar energy system the solar thermal energy storage tank losses and solar collector loop and solar storage loop warm-up/cool-down losses were predicted to be 63,000,000 BTU/year, or an average of 173,000 BTU/day. As discussed in Section VII, page 53 of this report, storage tank losses, piping losses, and energy delivered to the domestic hot water system currently range from 180,000 to 400,000 BTU/day as computed from data taken at the site. Because the portion of this energy delivered to the domestic hot water system is unknown, the remainder, i.e. storage tank and piping losses is also unknown. At this point, the original estimate of storage tank losses and solar collector loop and solar storage loop warm-up/cool-down losses appears reasonable. Our current estimate of these losses remains at 63,000,000 BTU/year..

E. Solar Collector Array Size

Columbia's technical proposal to U.S. DOE in November of 1976 proposed a solar energy collector array comprised of 12 rows and 3324 square feet. For the reasons discussed in Section V, pages 35-37 of this report, the actual installed solar collector array has 11 rows and 2978 square feet.

F. Solar Energy Collected

The solar collector efficiency for the first seven months of 1980 has averaged 33.8 percent of beam solar radiation, as discussed in Section VIII, page 59. Several improvements have been made to the solar collectors during the first five months of 1980 as discussed in Section VIII. It is now expected that the solar collector array will meet or exceed a 33.8 percent efficiency annually. The annual solar system energy collection can be calculated from the information in paragraphs B, C and E.

Proposed:

$$\begin{aligned}
 \text{Proposed Solar Energy Collected} &= \begin{bmatrix} \text{Predicted} \\ \text{Solar} \\ \text{Radiation} \\ \text{Available} \end{bmatrix} \times \begin{bmatrix} \text{Predicted} \\ \text{Annual} \\ \text{Solar} \\ \text{Collector} \\ \text{Efficiency} \end{bmatrix} \times \begin{bmatrix} \text{Proposed} \\ \text{Solar} \\ \text{Collector} \\ \text{Area} \end{bmatrix} \\
 &= 327,929 \times 0.58 \times 3324 \\
 &= 632 \text{ million BTU/year}
 \end{aligned}$$

Current Estimate:

$$\begin{aligned}
 \text{Current Estimate of Solar Energy Collected} &= \begin{bmatrix} \text{Actual} \\ \text{Solar} \\ \text{Radiation} \\ \text{Available} \end{bmatrix} \times \begin{bmatrix} \text{Actual} \\ \text{Annual} \\ \text{Solar} \\ \text{Collector} \\ \text{Efficiency} \end{bmatrix} \times \begin{bmatrix} \text{Actual} \\ \text{Solar} \\ \text{Collector} \\ \text{Area} \end{bmatrix} \\
 &= 262,063 \times 0.338 \times 2978 \\
 &= 264 \text{ million BTU/year}
 \end{aligned}$$

G. Solar Energy Utilization

The annual solar energy utilization can be calculated from the information in paragraphs D and F.

Proposed:

$$\begin{aligned}
 \text{Proposed Solar Energy Utilization} &= \left[\begin{array}{c} \text{Predicted} \\ \text{Solar} \\ \text{Energy} \\ \text{Collected} \end{array} \right] - \left[\begin{array}{c} \text{Predicted} \\ \text{Solar} \\ \text{System} \\ \text{Losses} \end{array} \right] \\
 &= 632,000,000 - 63,000,000 \\
 &= 569,000,000 \text{ BTU/year}
 \end{aligned}$$

Current Estimate:

$$\begin{aligned}
 \text{Current Estimate of Solar Energy Utilization} &= \left[\begin{array}{c} \text{Current} \\ \text{Estimate of} \\ \text{Solar Energy} \\ \text{Collected} \end{array} \right] - \left[\begin{array}{c} \text{Current} \\ \text{Estimate of} \\ \text{Solar System} \\ \text{Losses} \end{array} \right] \\
 &= 264,000,000 - 63,000,000 \\
 &= 201,000,000 \text{ BTU/year}
 \end{aligned}$$

H. Solar Energy Fraction

The solar fraction as computed for the technical proposal can be calculated from the information in paragraphs A and G.

Proposed:

$$\begin{aligned}
 \text{Proposed Solar Fraction} &= \frac{\text{Proposed Solar Energy Utilization}}{\text{Building Thermal Demand}} \\
 &= \frac{569,000,000}{1,728,000,000} \\
 &= 0.33
 \end{aligned}$$

Current Estimate:

$$\begin{aligned}
 \text{Current Estimate of Solar Fraction} &= \frac{\text{Current Solar Energy Utilization}}{\text{Current Building Thermal Demand}} \\
 &= \frac{201,000,000}{2,961,000,000} \\
 &= 0.07
 \end{aligned}$$